Arctic clouds, circulation and sea ice during 2007 and beyond

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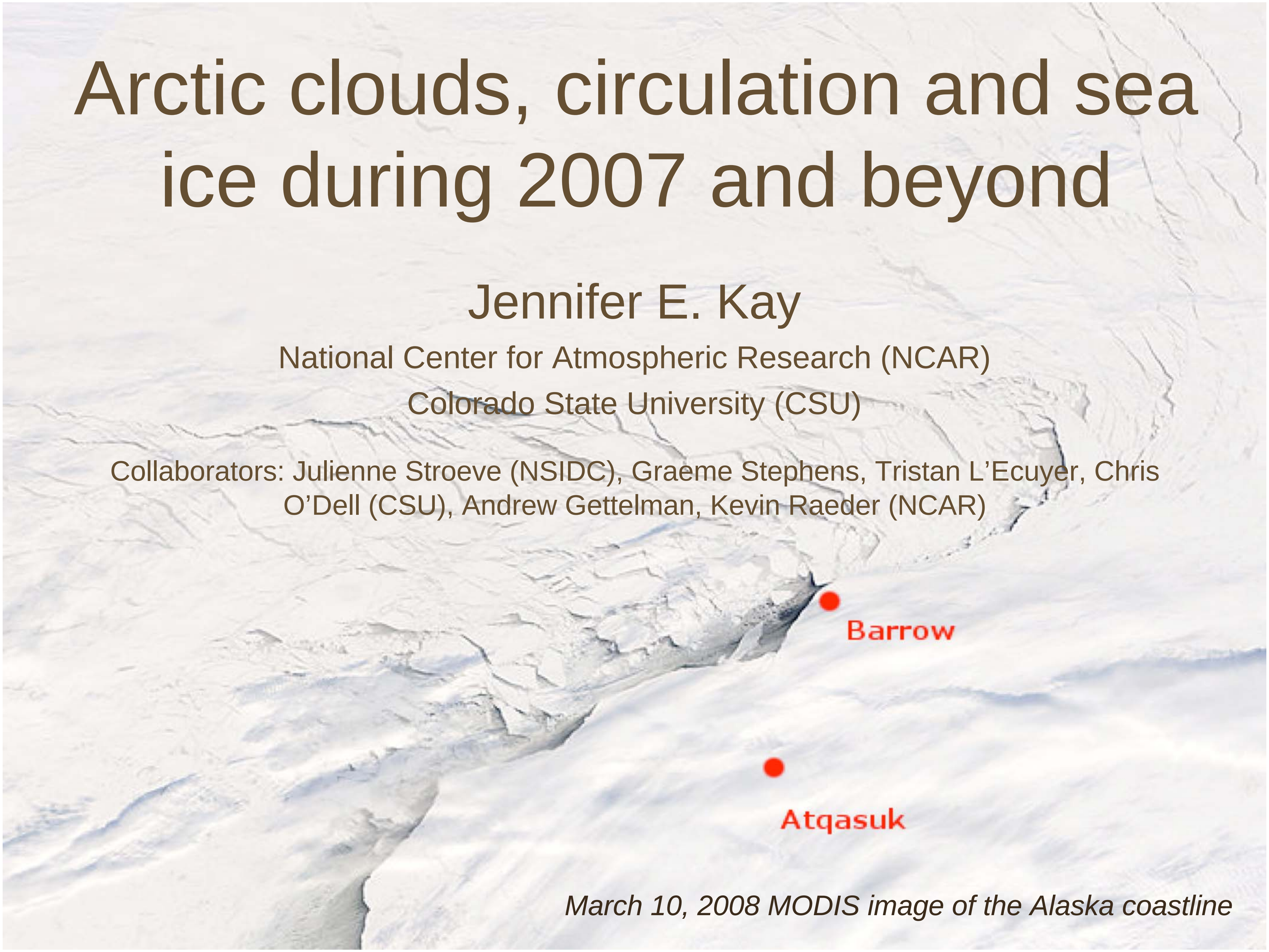
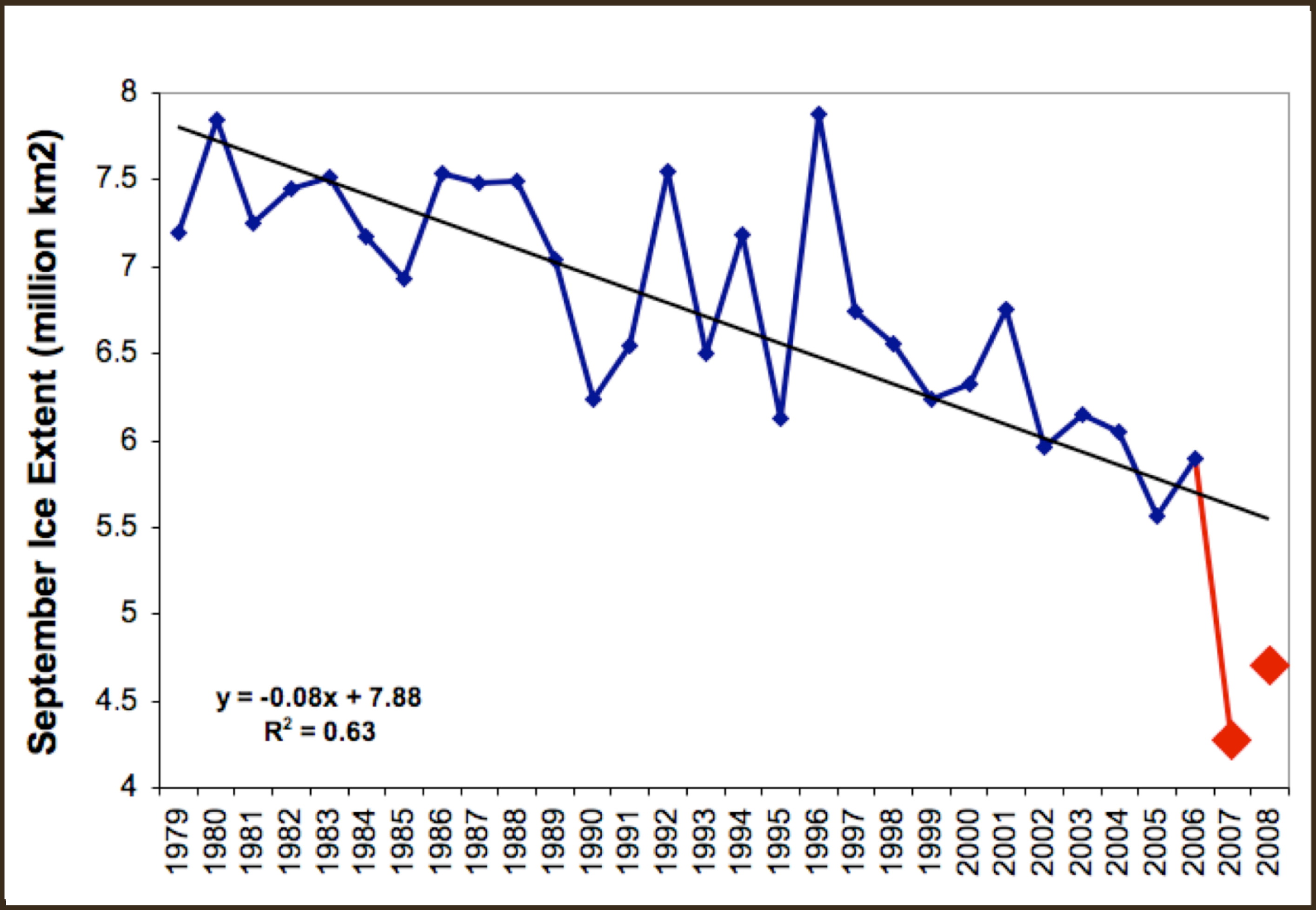


March 10, 2008 MODIS image of the Alaska coastline

September Ice Extent Timeseries

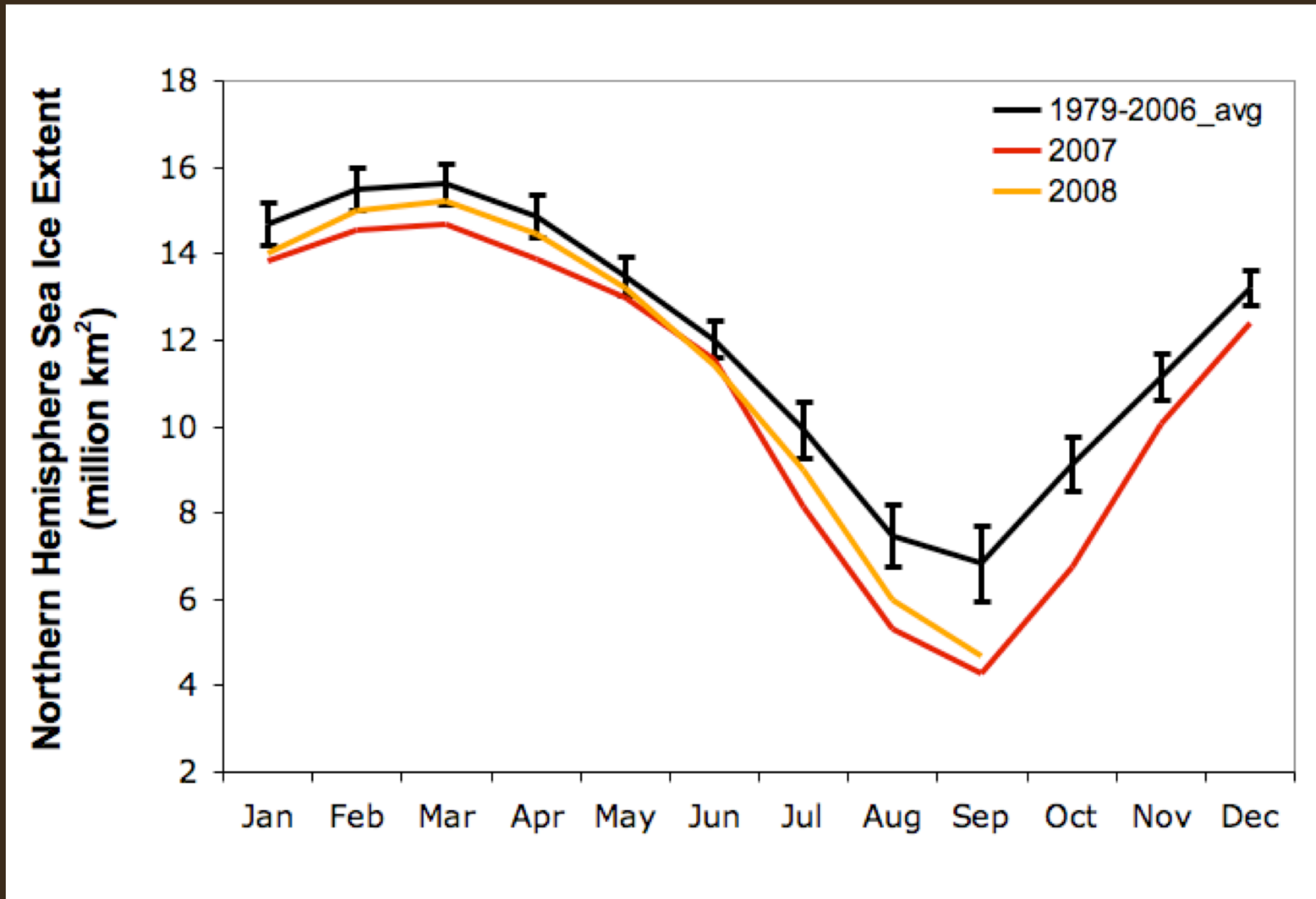


Data from NSIDC

The 2007 minimum was 4.13 million km², -43% from 1979 and -26% from 2005.

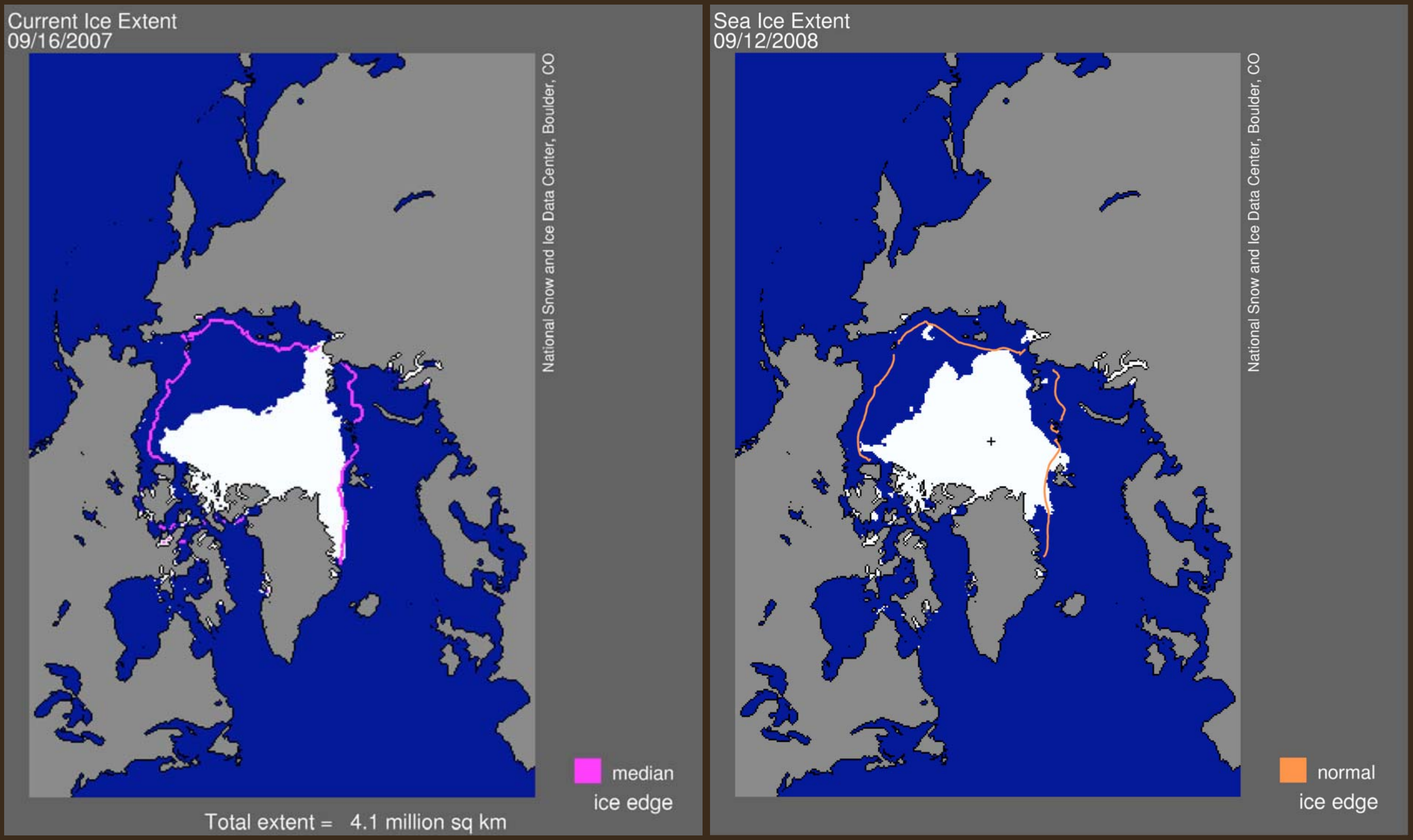
The 2008 minimum was 4.52 million km², +9% from 2007.

Seasonal Variations in Ice Extent



Data from NSIDC

A New Arctic Environment



Plots from NSIDC

Declining sea ice creates new challenges and opportunities.

What controls sea ice extent?

SEA ICE THICKNESS!

At the beginning of the annual melt (March), multi-year ice can be 6+ m thick, while seasonal ice is only ~1-2 m thick.

Dynamic Factors (sea ice motion):

-Winds move and break up sea ice

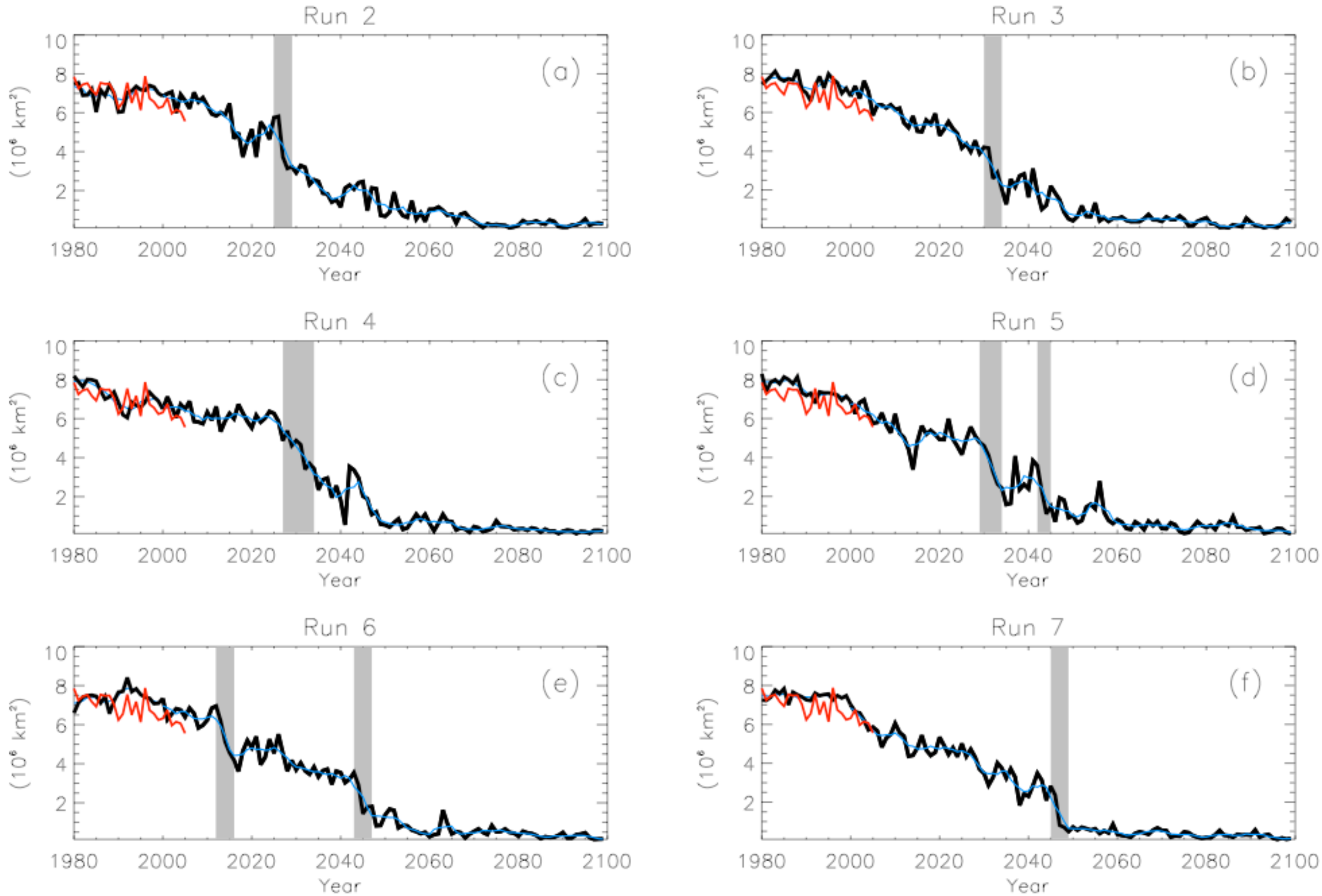
-Winds can also enhance ice export out of the Arctic

Thermodynamic Factors (heat):

-Heat from the ocean and the atmosphere

-Heat comes from lower latitudes (advection) and local heat sources (sun)

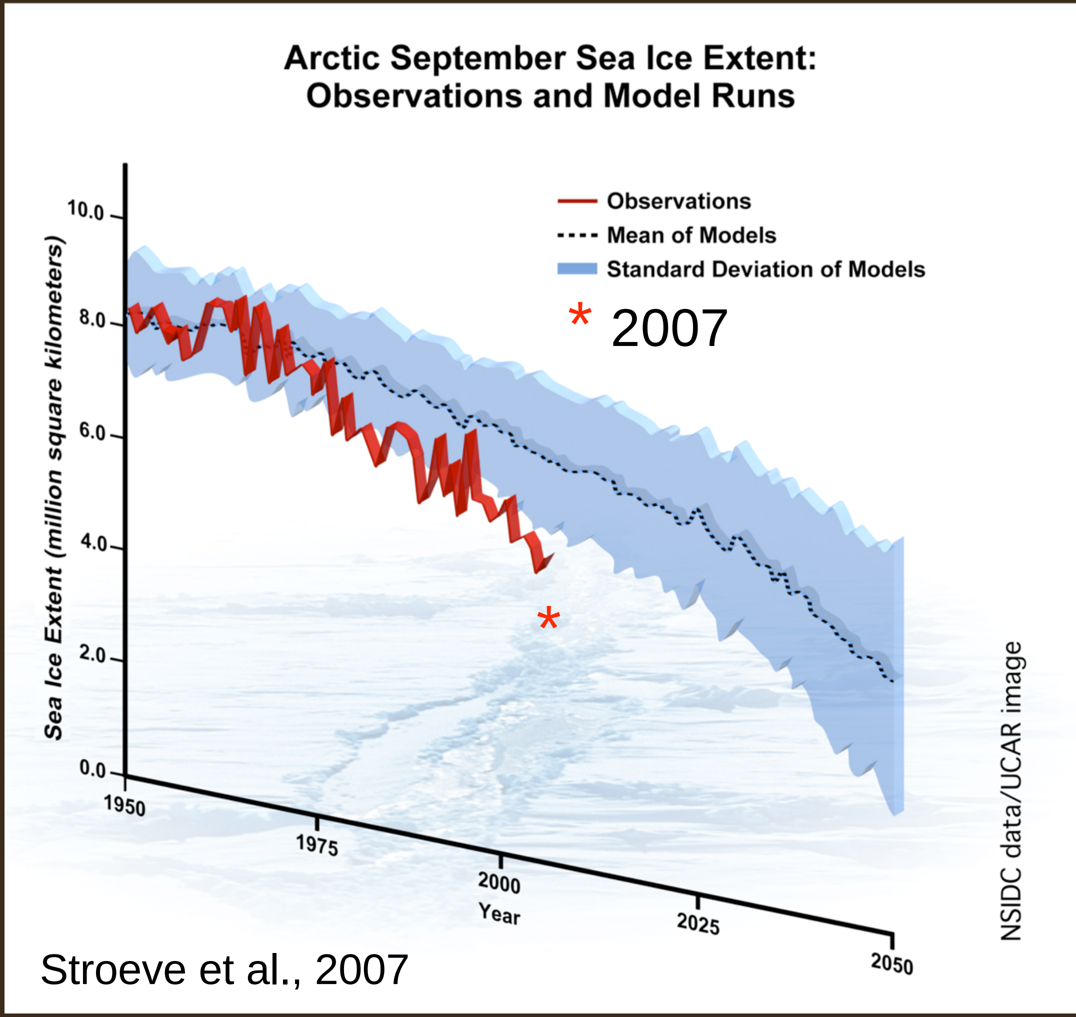
Abrupt sea ice extent reductions do occur in climate models



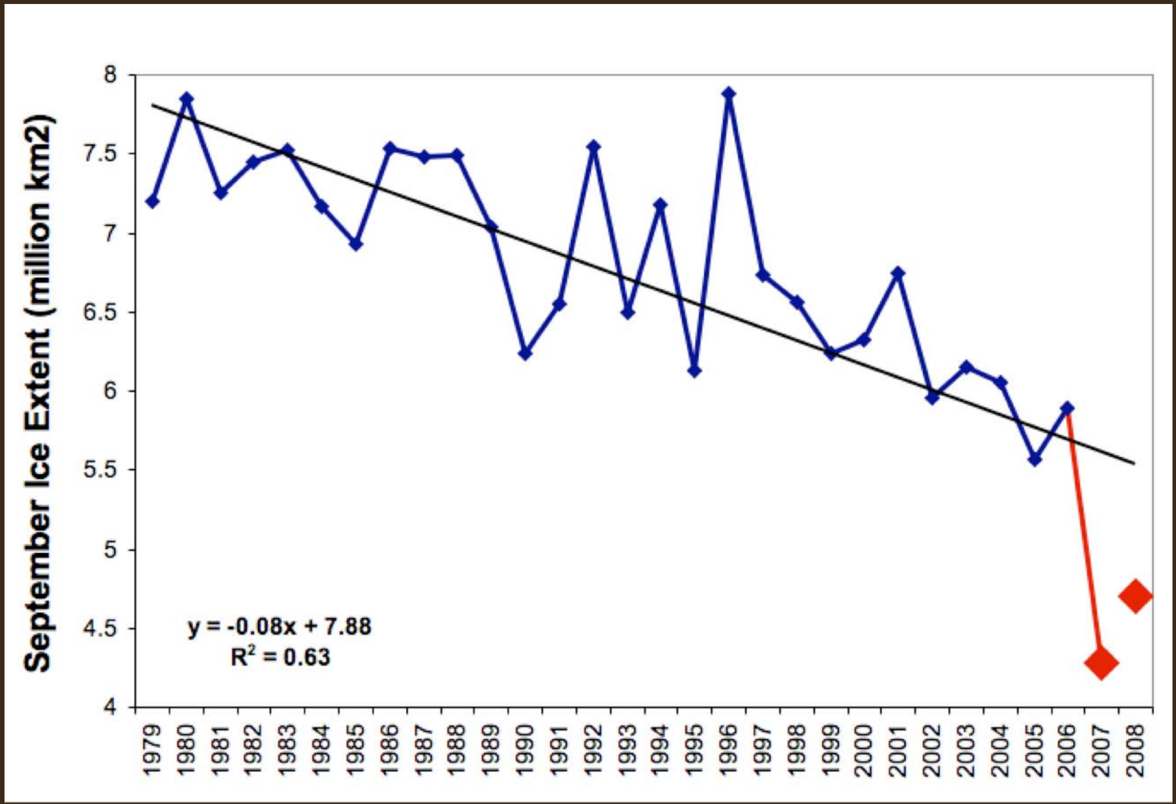
Satellite observations
NCAR climate model

Figure from Holland et al., 2006

Arctic sea ice decline is faster than predicted by climate models…

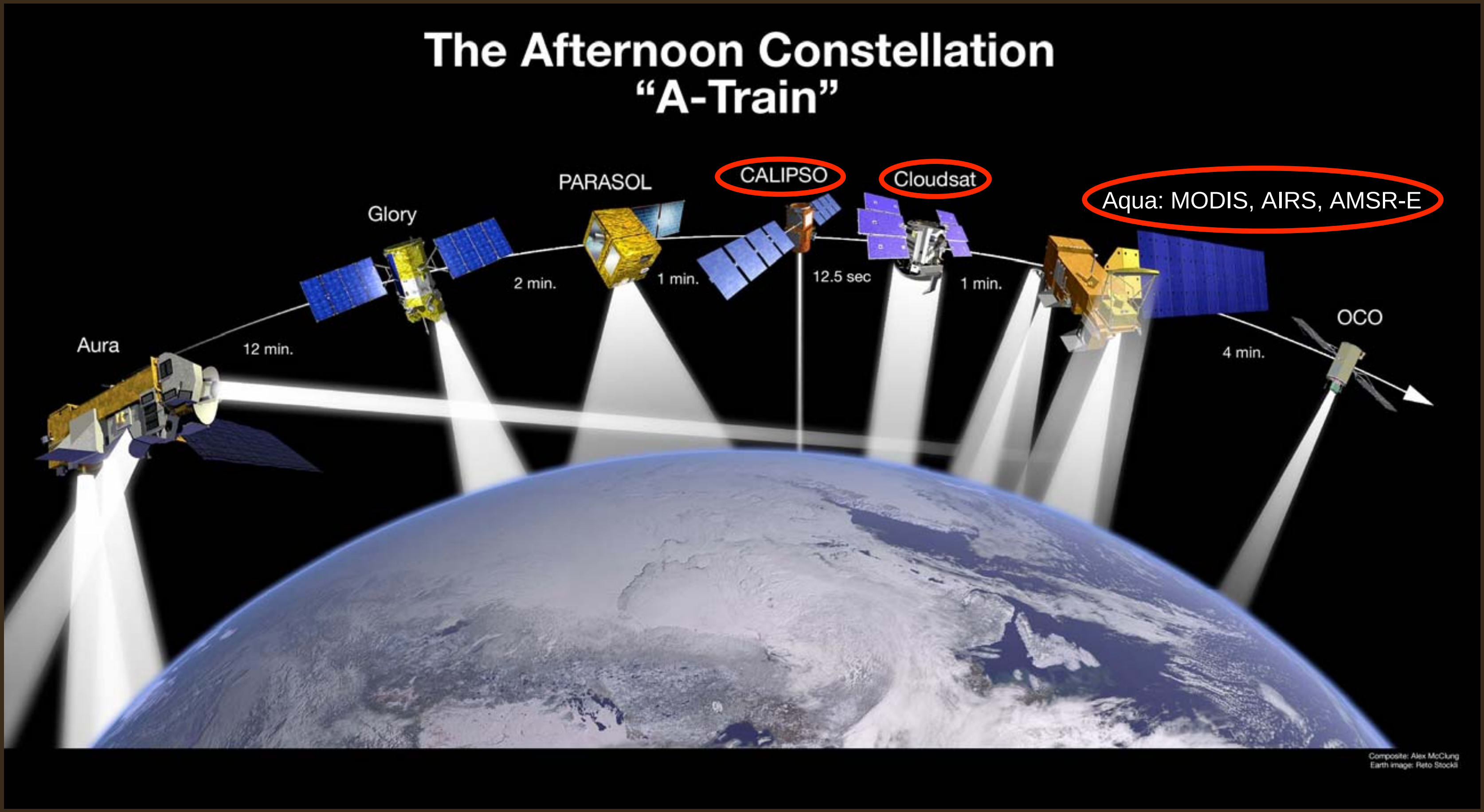


Many questions

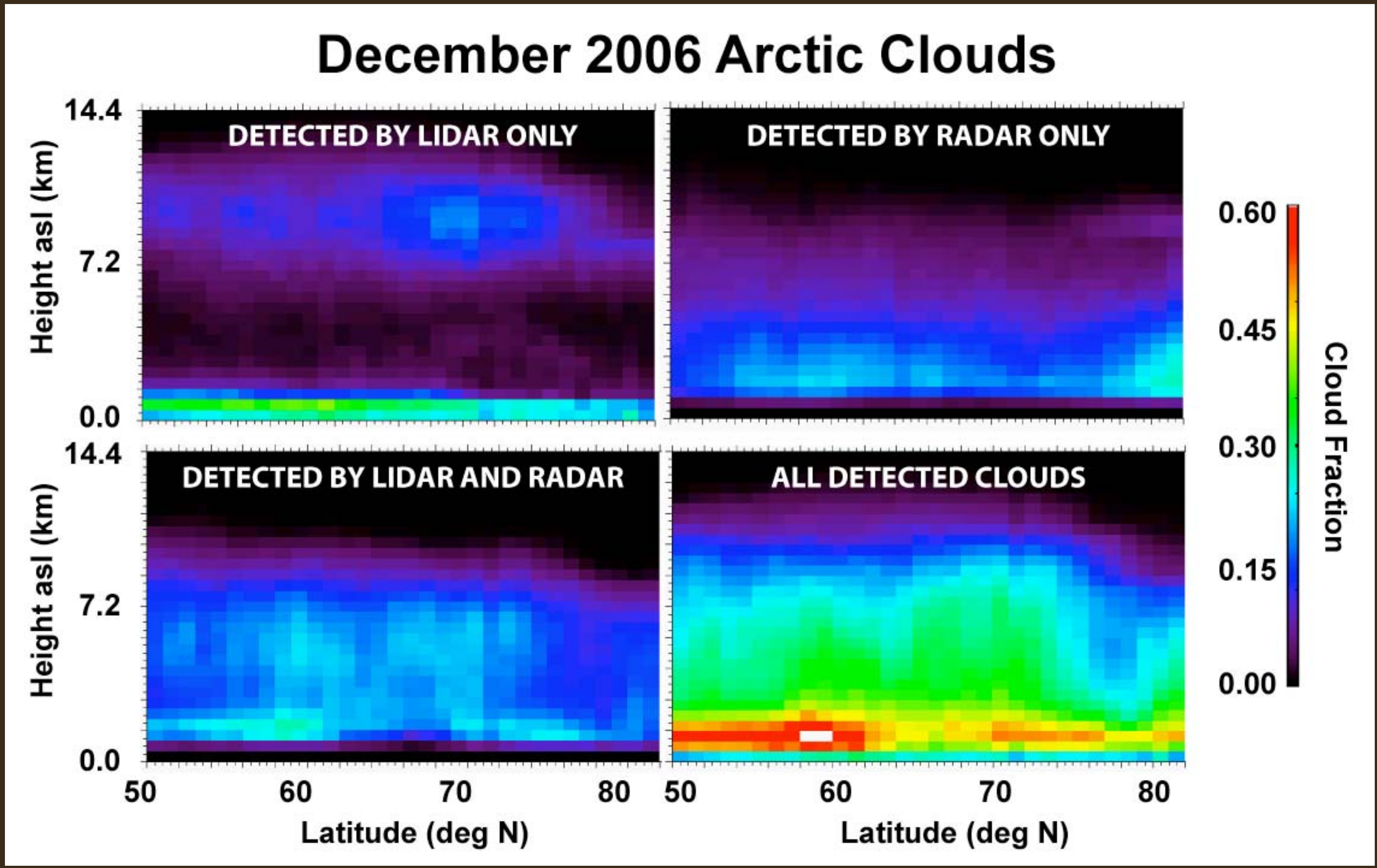


1) thermodynamic vs. dynamic ice loss processes
2) natural variability vs. greenhouse warming
3) cloud-ice-circulation feedbacks
4) have we reached a “tipping point”?

1. New observations and tools
2. Mechanisms for recent sea ice loss
3. Arctic CAM-DART project



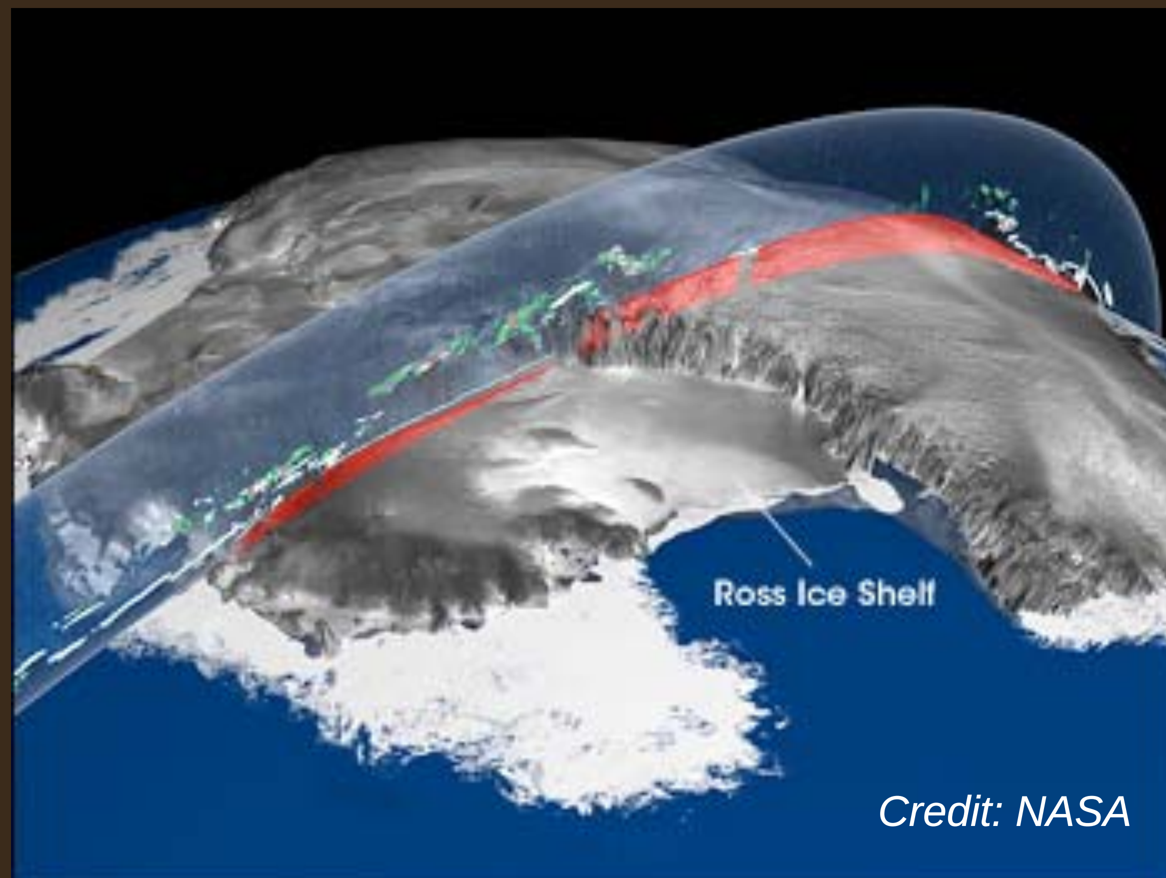
CloudSat and CALIOP synergy



Together, spaceborne radar and lidar detect most clouds.

Ice freeboard observations from a spaceborne laser altimeter

IceSat data are being used to estimate sea ice freeboard.



Credit: NASA

New Tool: Data Assimilation

CAM = Community Atmosphere Model
DART = Data Assimilation Research Testbed

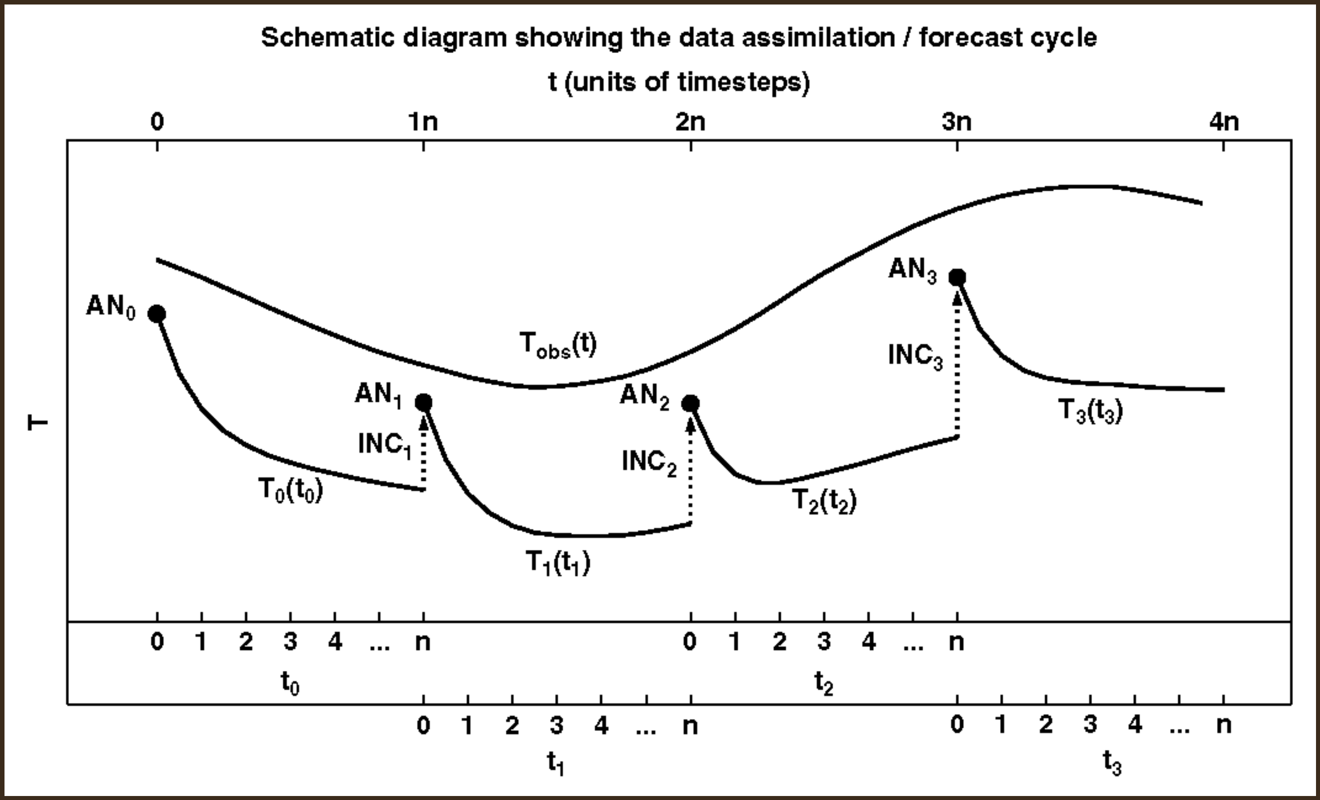
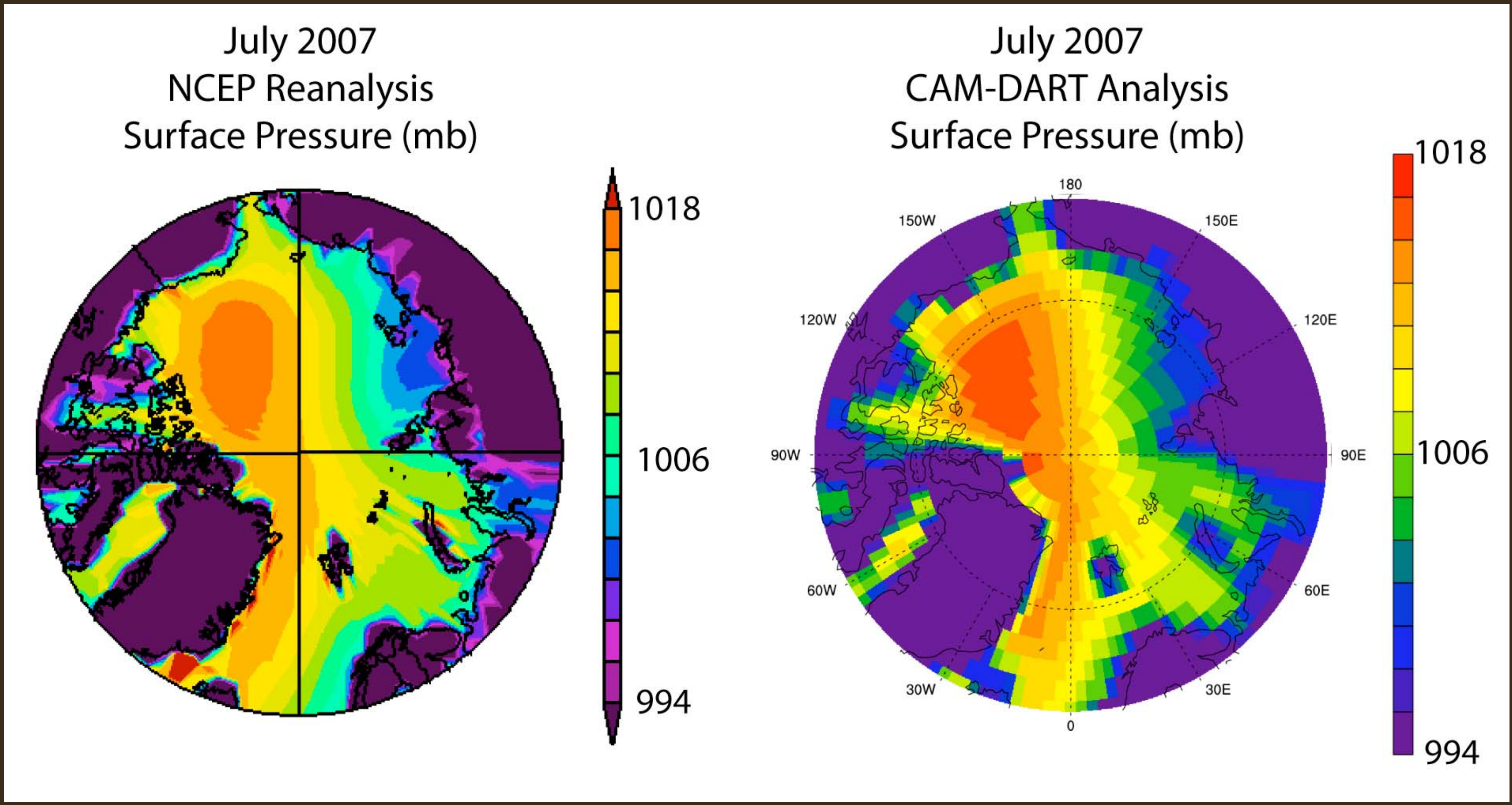


Fig. 1 from Rodwell and Palmer (2007)

Lots of science and model assessment can be done!

- Do climate models capture observed atmospheric processes?
- Do analysis increments reveal the underlying mechanisms for persistent model biases?

NCEP vs. CAM-DART
July 2007

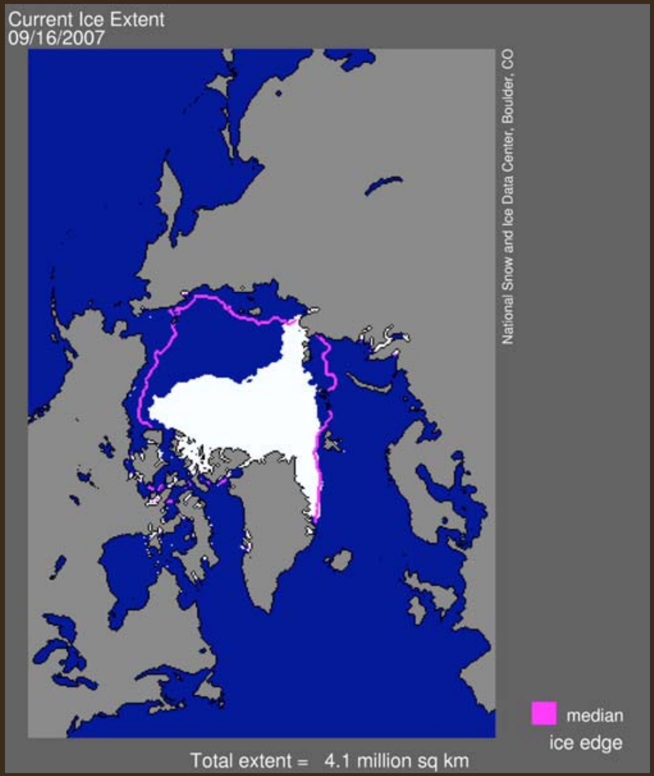


CAM-DART and NCEP reanalysis show similar surface pressure patterns.

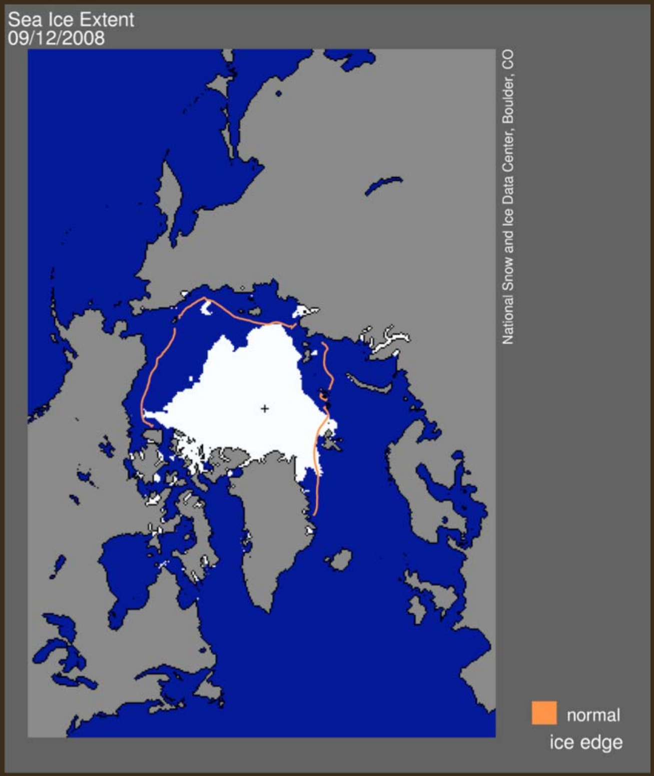
1. New observations

2. Mechanisms for recent sea ice loss

3. Arctic CAM-DART project



The 2007 record minimum extent was 4.13 million km^2.



The 2008 minimum extent was 4.52 million km^2.

March 2007 sea ice thickness

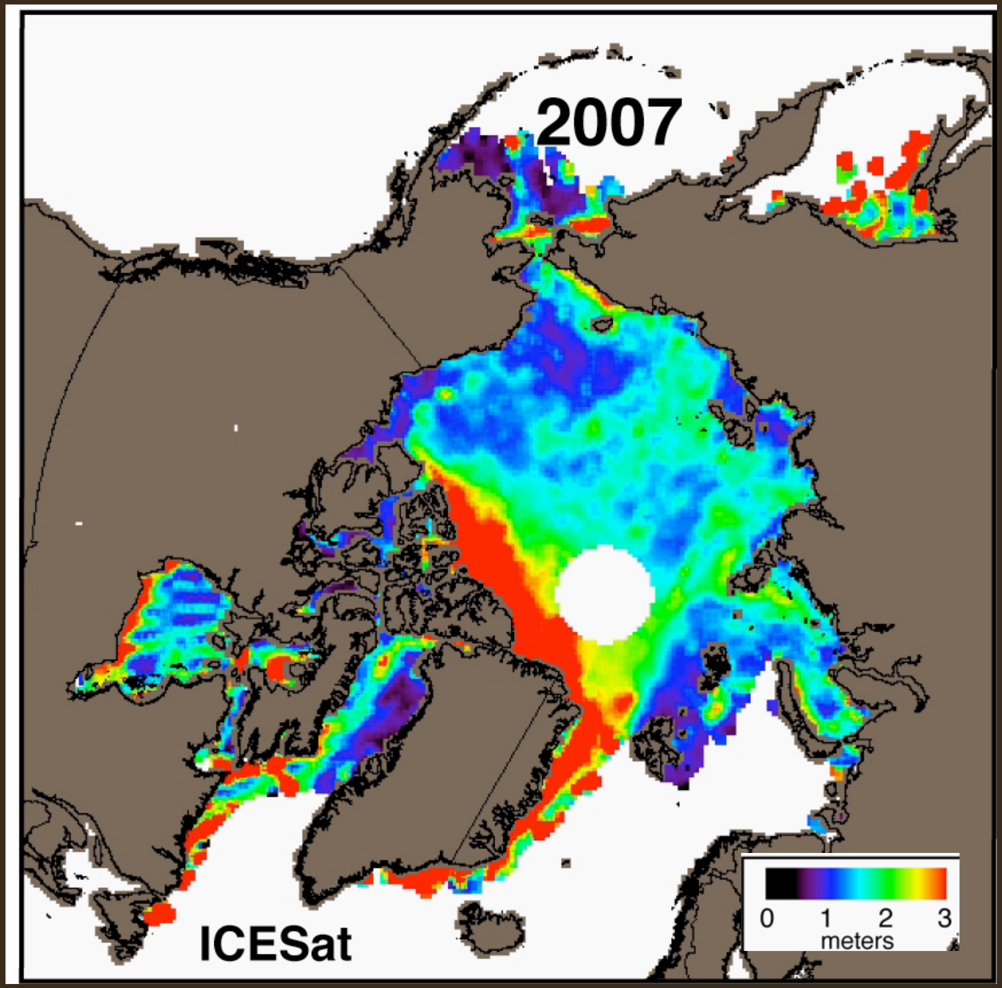


Figure from Stroeve et al. (2008)
courtesy M. Holland

2007 Arctic melt season atmospheric circulation pattern

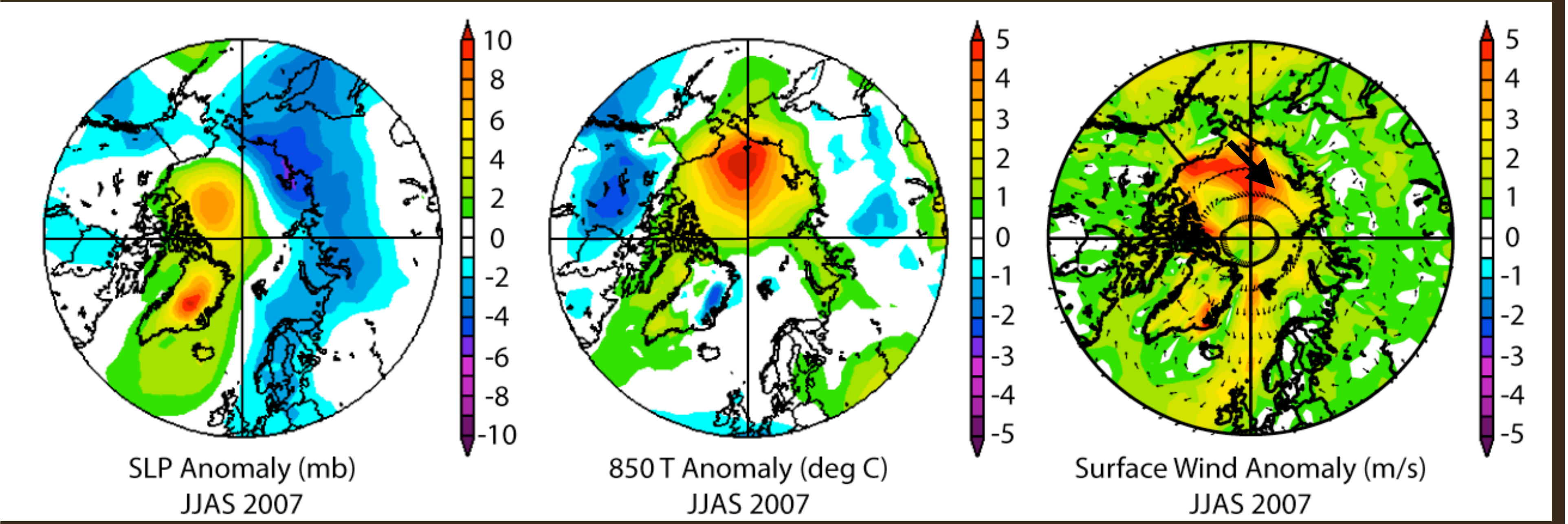
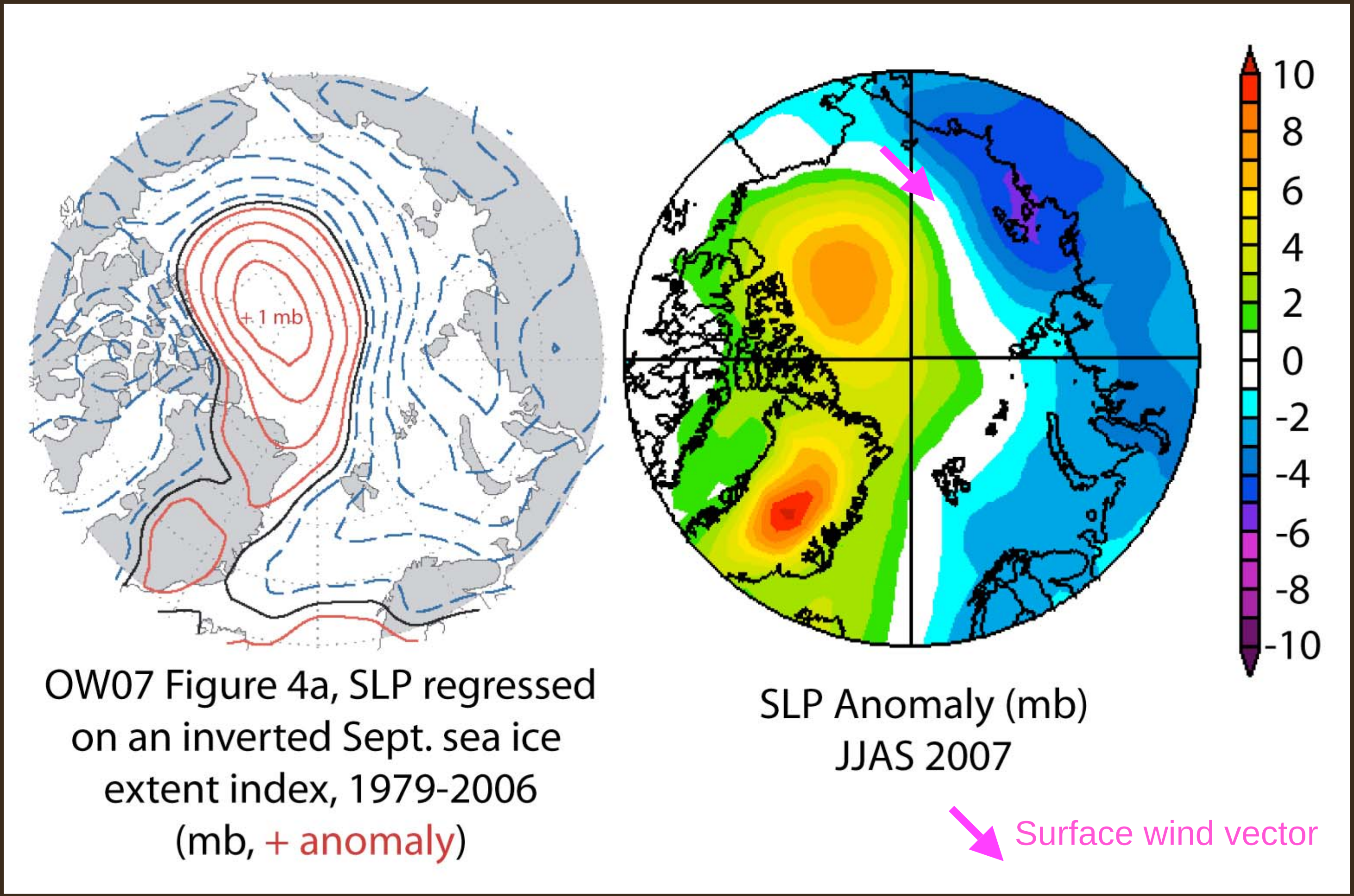


Figure 4, Kay et al. (2008)

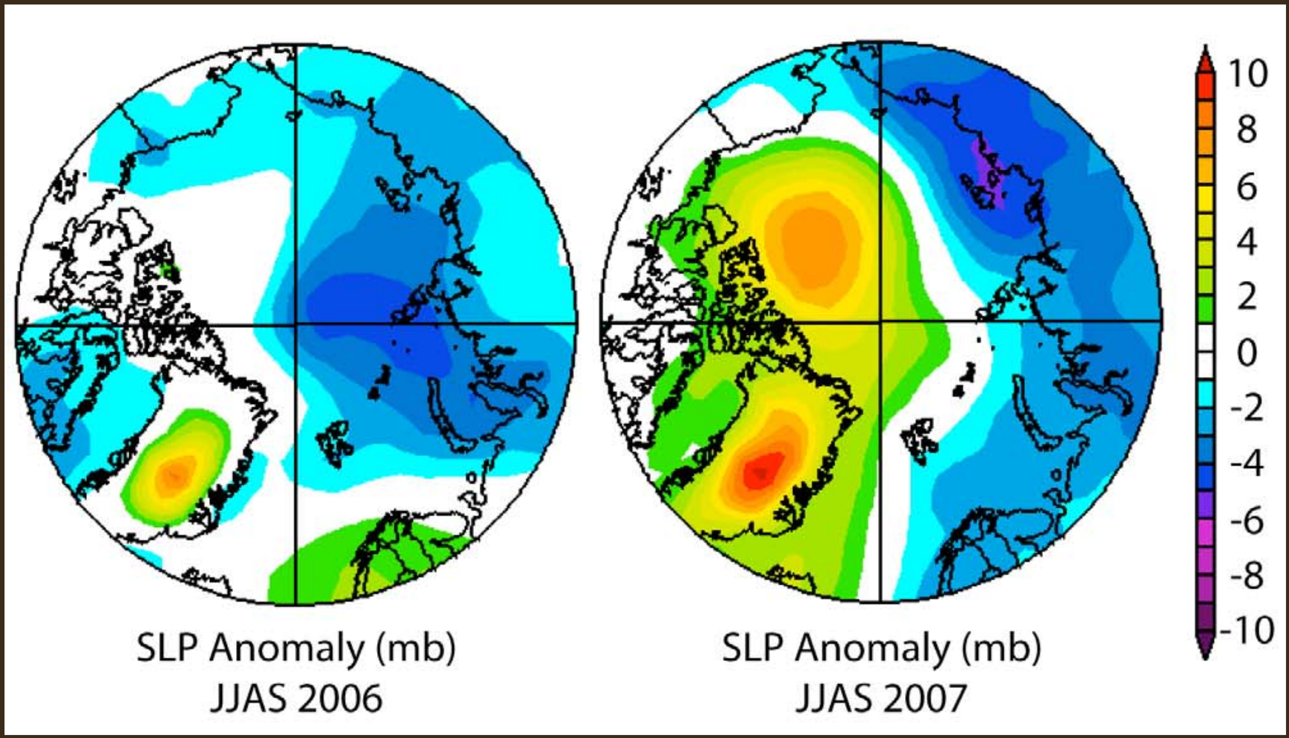
Positive sea level pressure (SLP), high temperatures (T), and strong southerly wind anomalies contributed to the dramatic sea ice loss during the 2007 melt season.

Summertime circulation and ice loss



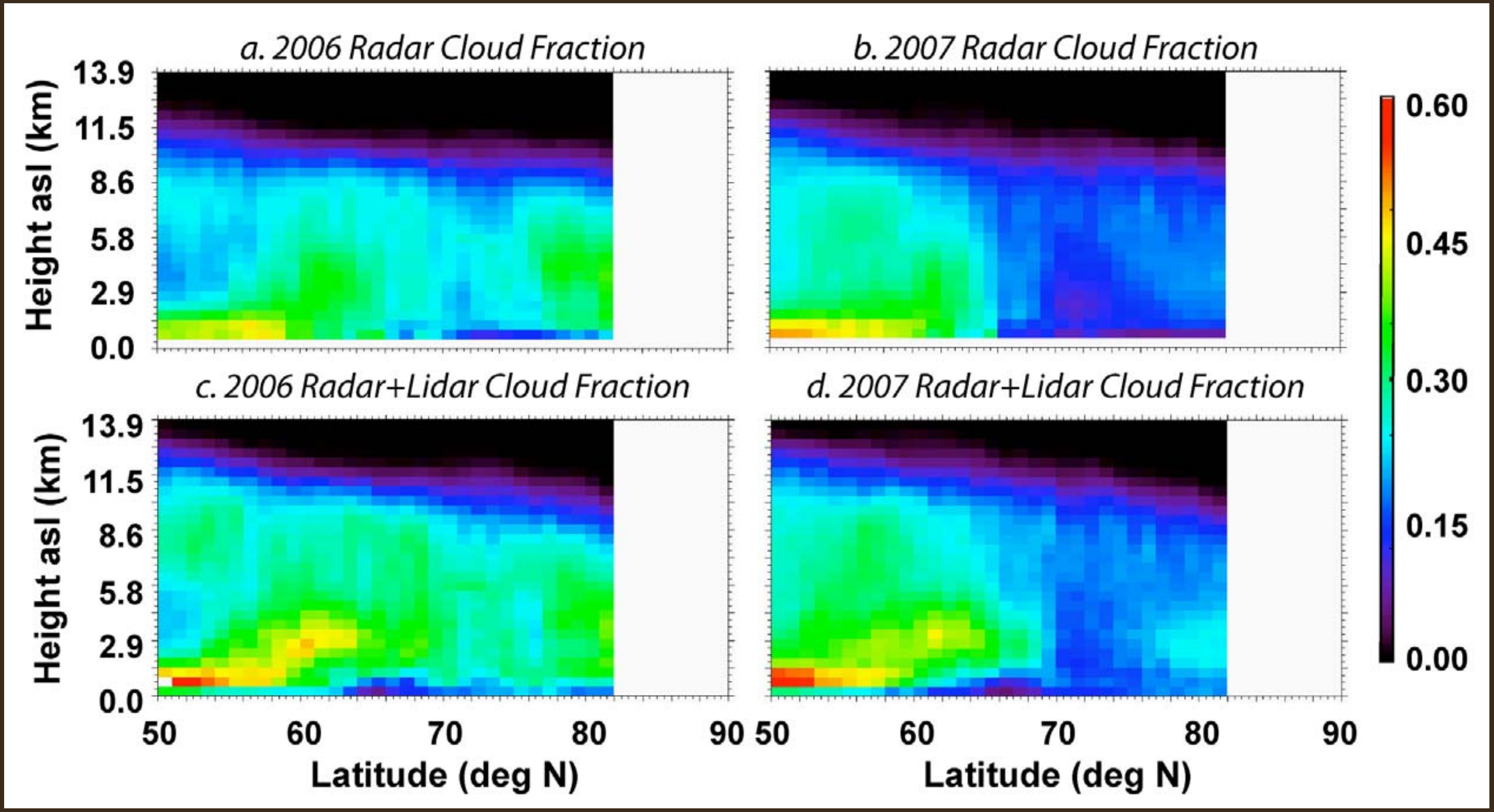
Ogi and Wallace 2007 (OW07) attribute sea ice loss to wind stress. Our work suggests additonal contributing factors.

Recent summer circulation patterns



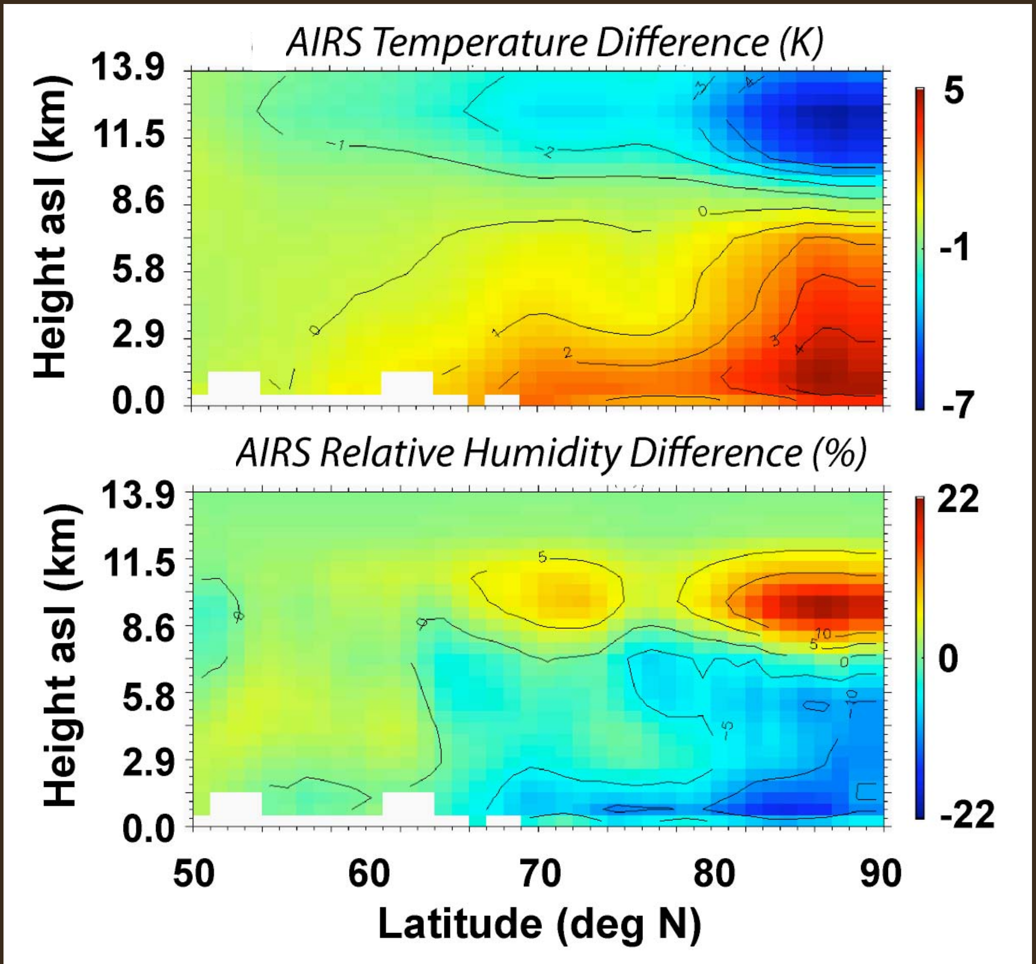
CloudSat radar and CALIOP lidar data are available from June 2006 to present.

2007 Western Arctic cloud reductions



CloudSat/CALIOP data reveal reduced cloudiness from 2006 to 2007 associated with the differing circulation patterns.

Why did the clouds go away?



AIRS data from Andrew Gettelman

AIRS data reveal a warmer and drier Western Arctic atmosphere in 2007 as compared to 2006.

Cloud and radiative flux differences (2007-2006)

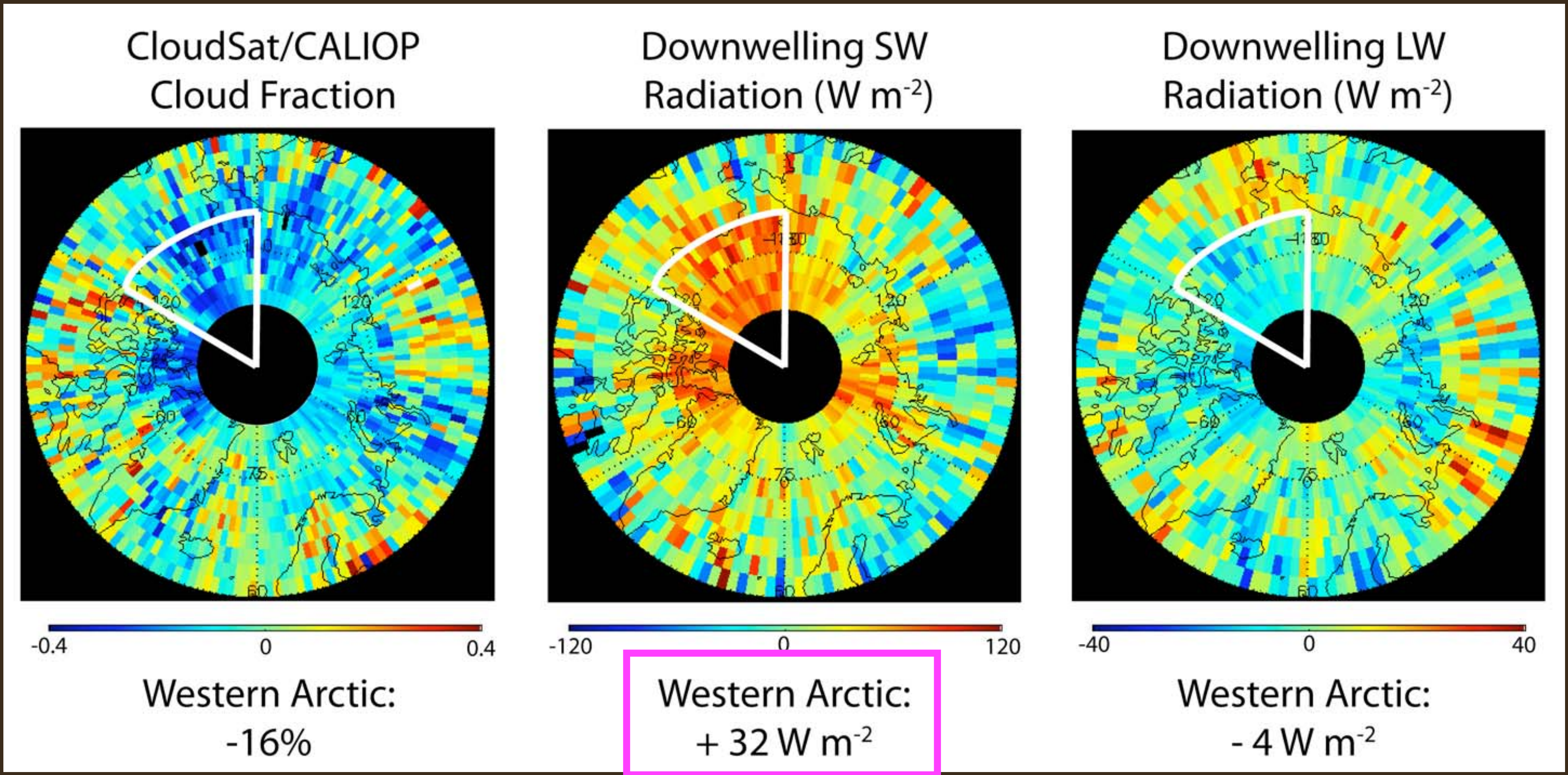


Figure 2, Kay et al. (2008)

“Back-of-the envelope” calculations

Simple calculations in Kay et al. (2008) suggest ~0.3 m of surface melt and ~2.4 deg K of upper ocean warming would result from the observed 2007-2006 downwelling flux differences.

Observed surface ocean warming

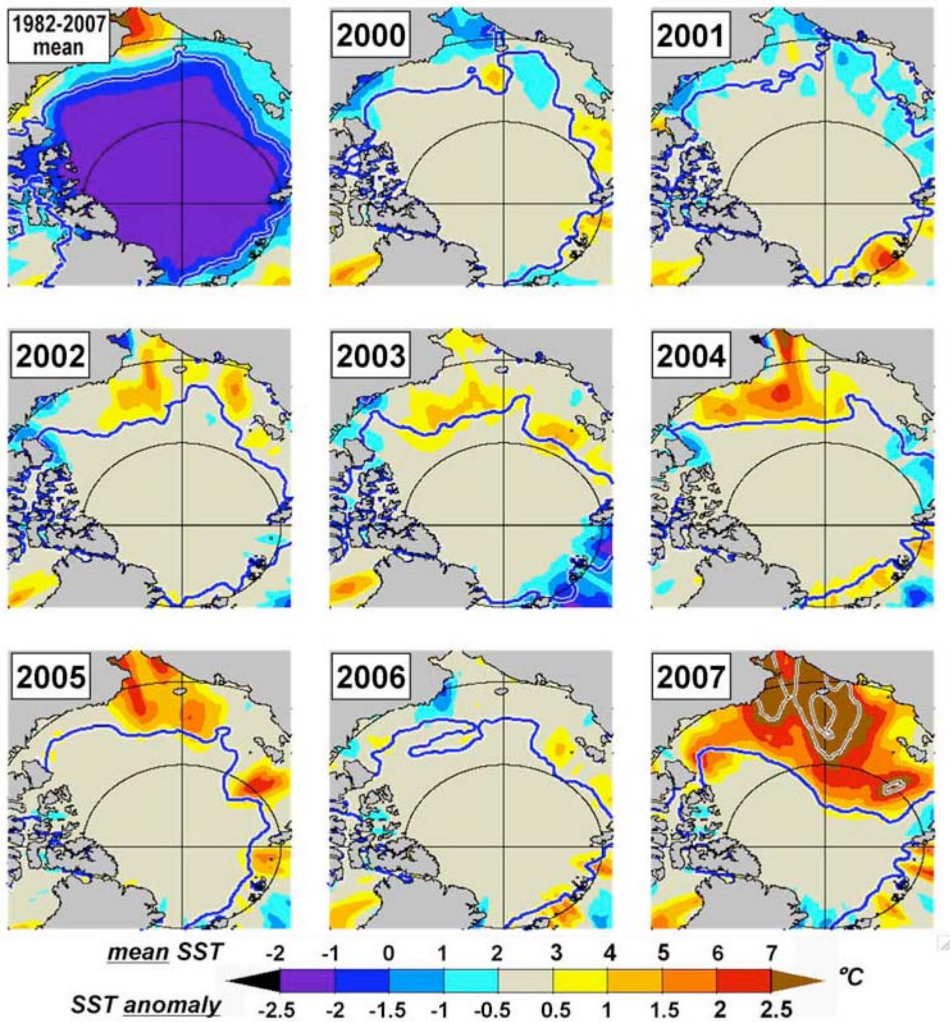
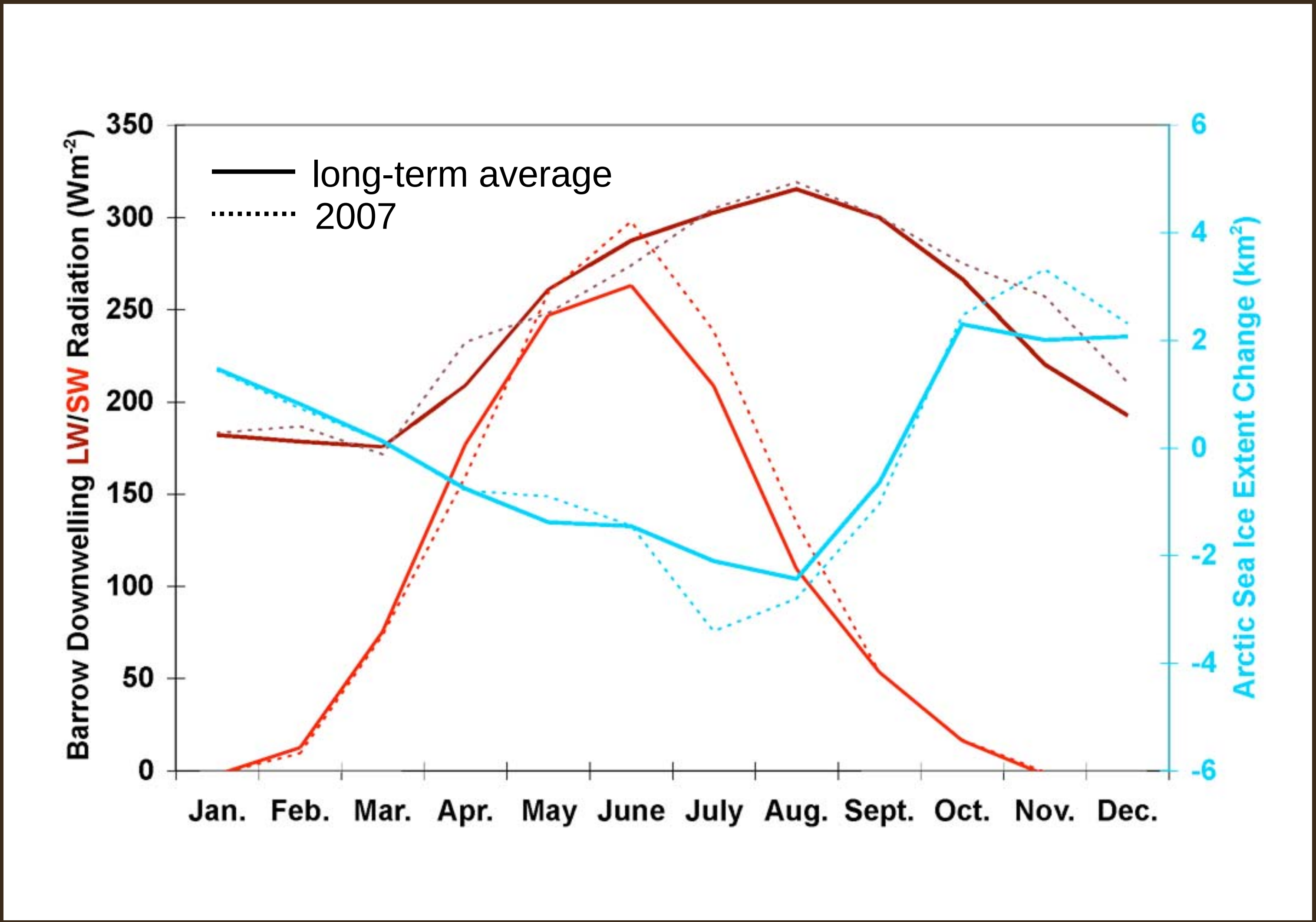


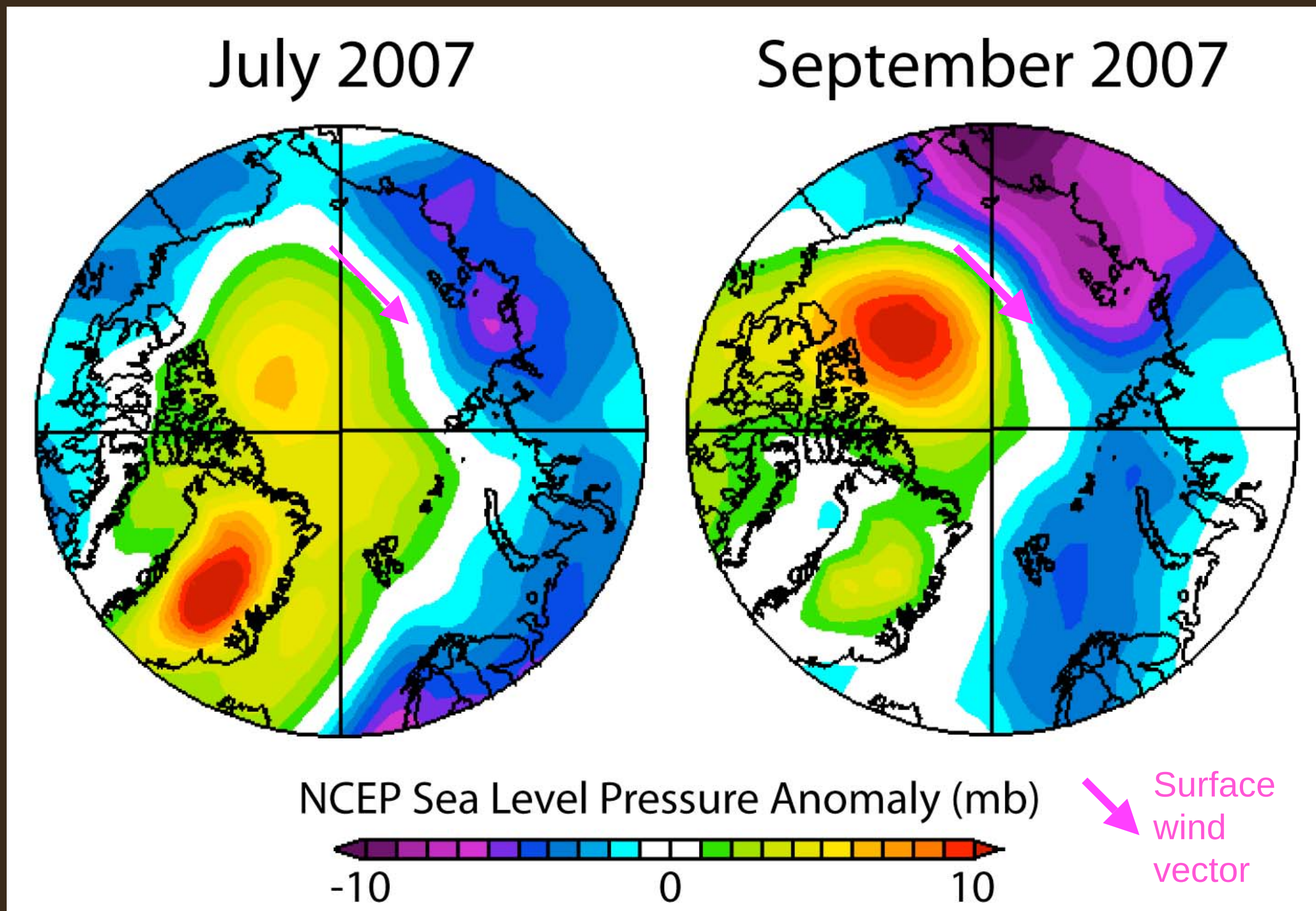
Figure 3. (top left) Mean satellite-derived summer SST [*Reynolds et al.*, 2002] and anomalies from this mean over 2000 2007, with no bias correction as in Figure 2. Latitudes 70°N and 80°N and longitudes 0°/180°E and 90°/270°E are shown. For 2007, extra contours for 3°C and 4°C are provided. Also shown is the September-mean ice edge (blue contour) from the Hadley Centre (1982 2006: http://badc.nerc.ac.uk/data/hadisst/) and from the National Centers for Environmental Prediction (2007: ftp://polar.ncep.noaa.gov/pub/cdas/).

Figure from Steele et al. (2008, GRL)

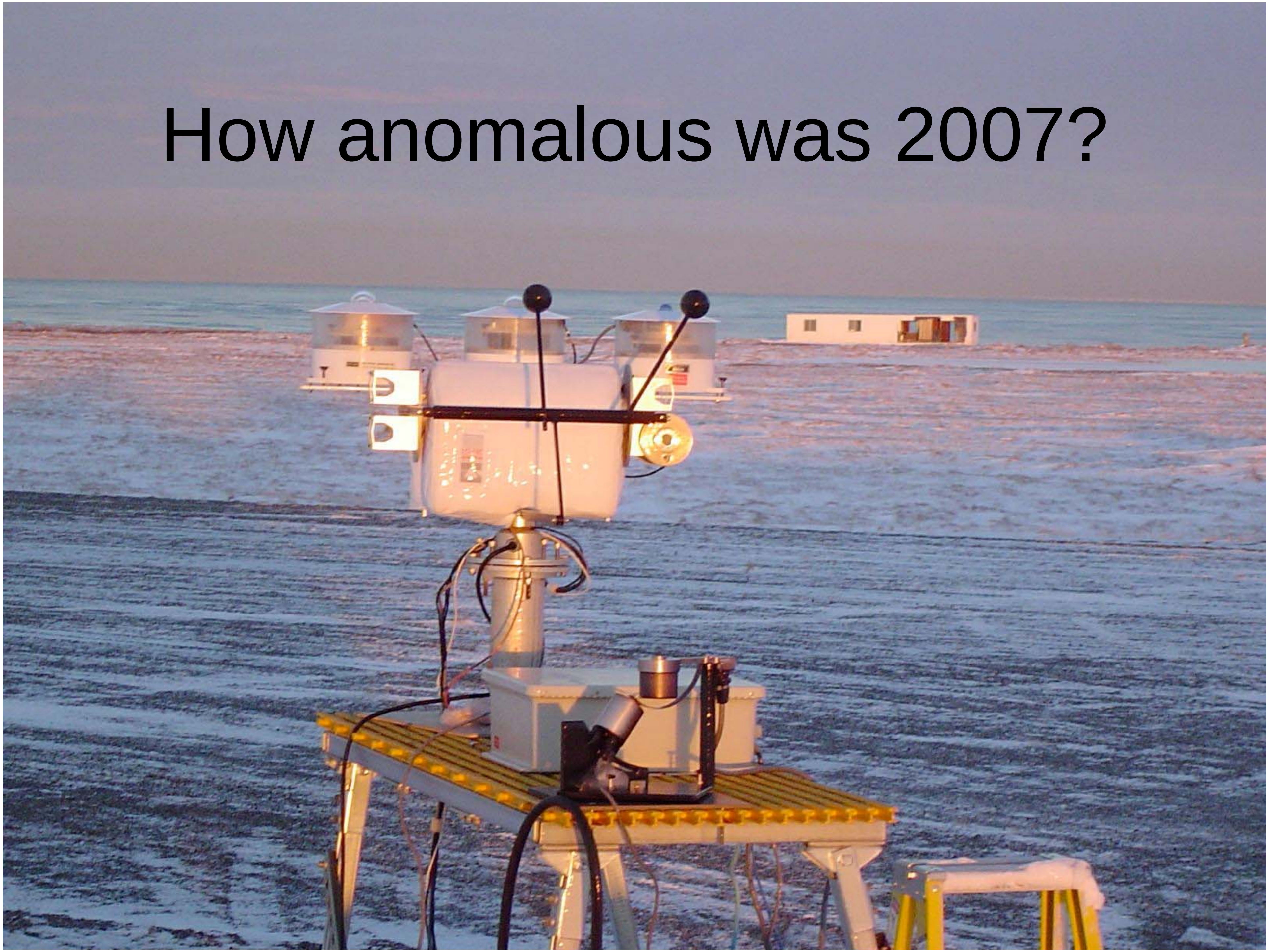
For clouds and ice albedo feedbacks, seasonal timing is key.



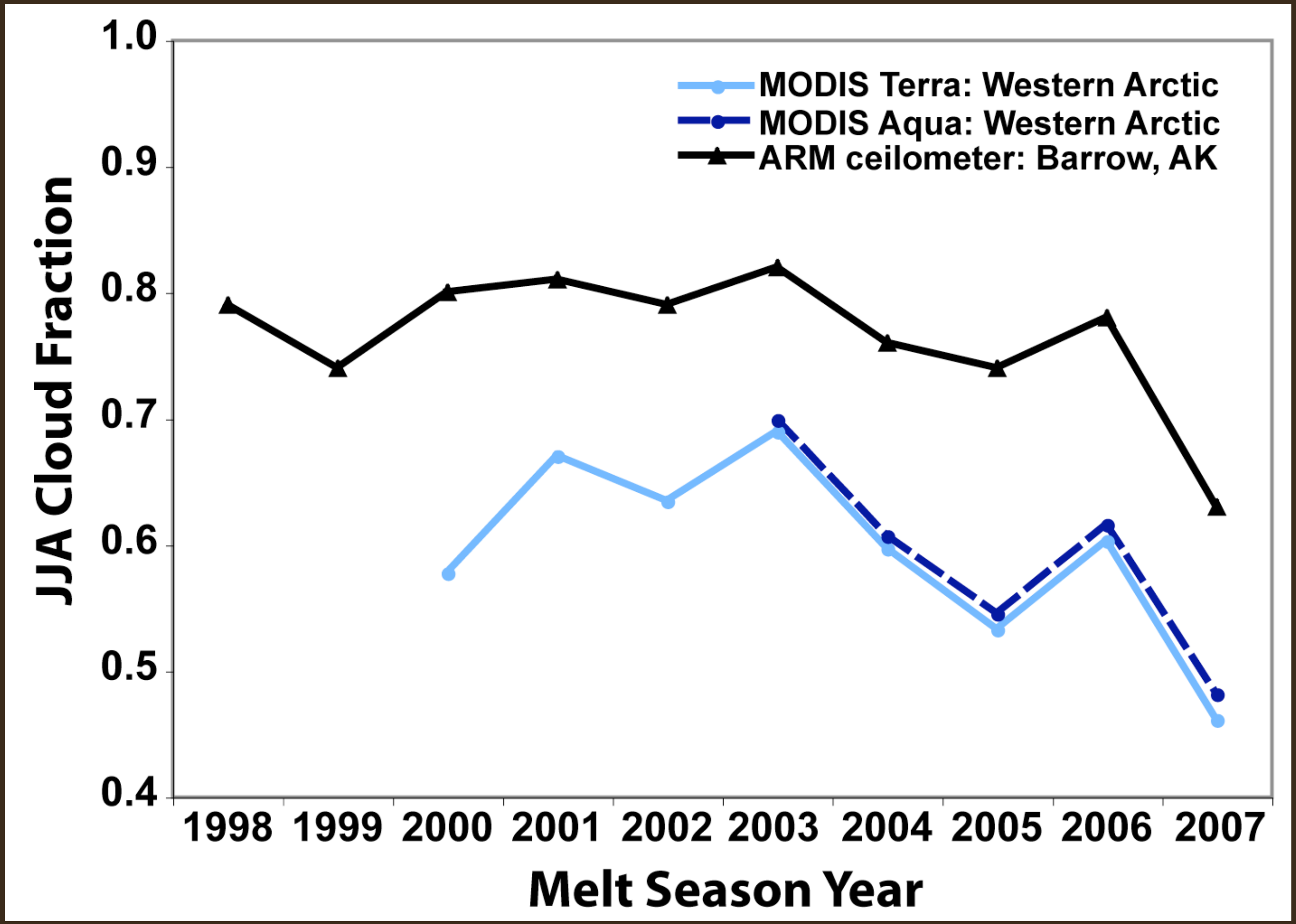
2007 SLP anomaly intensification



How anomalous was 2007?

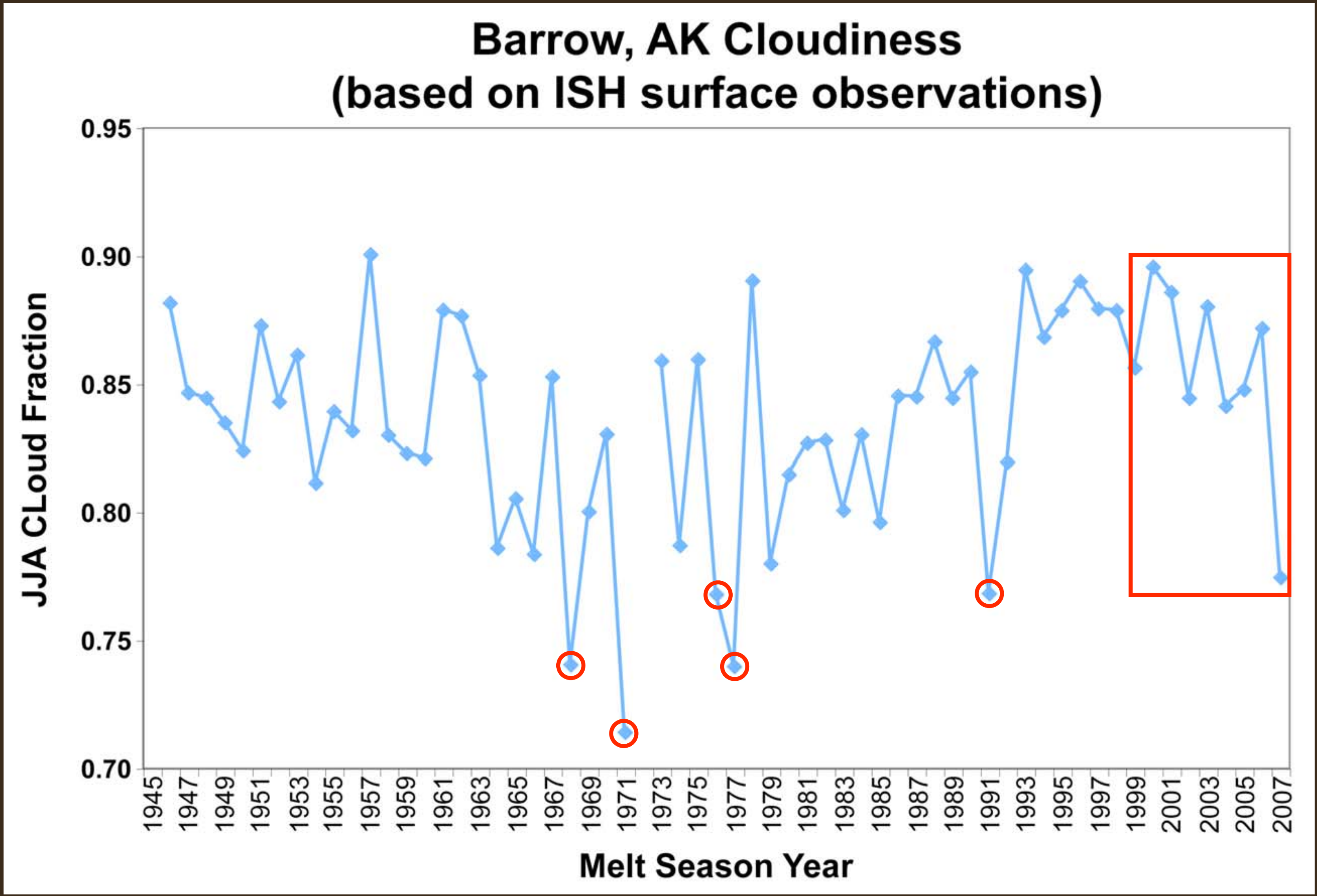


Recent Arctic cloud observations

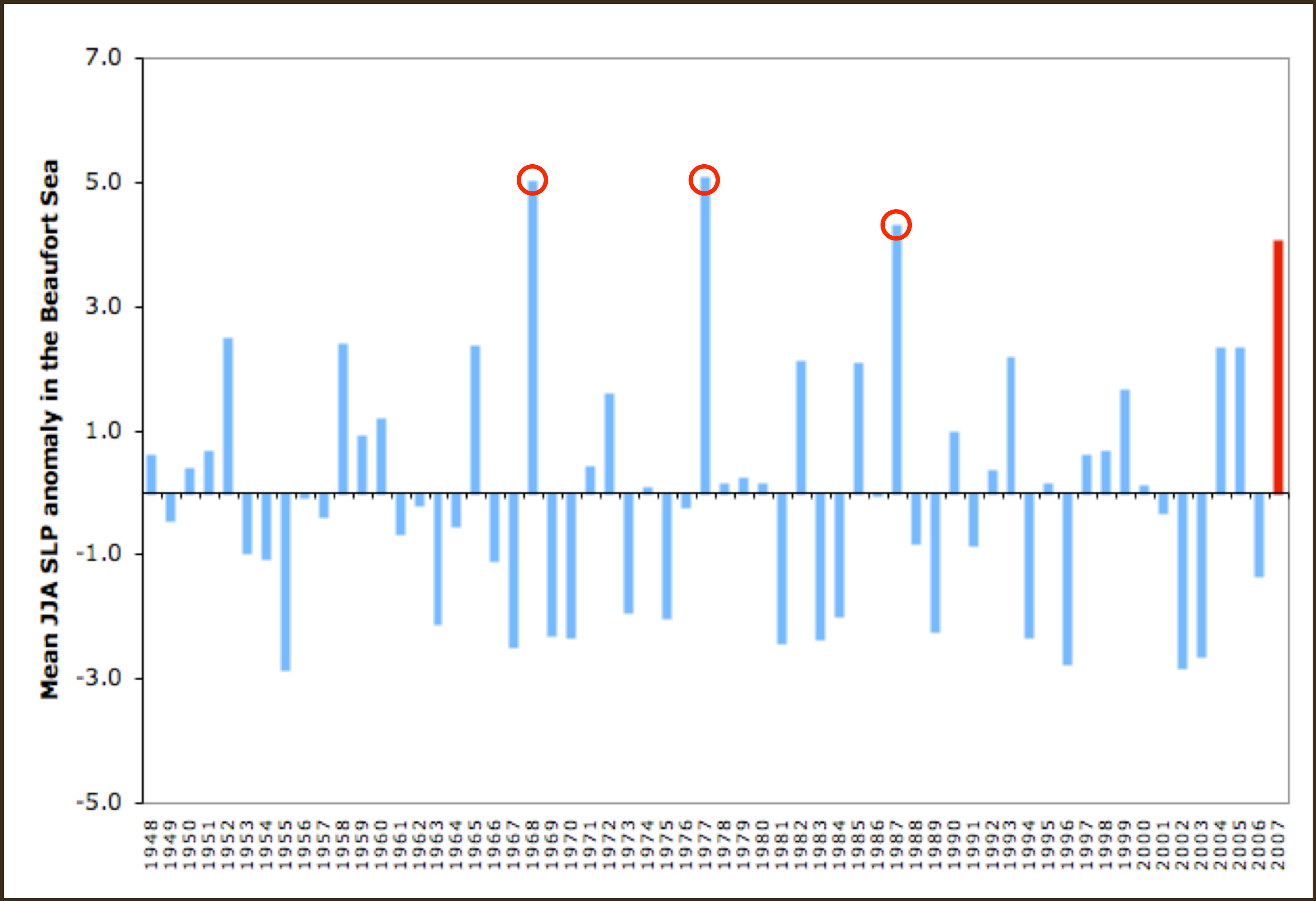


The 2007 cloud fraction is anomalous in the recent past.

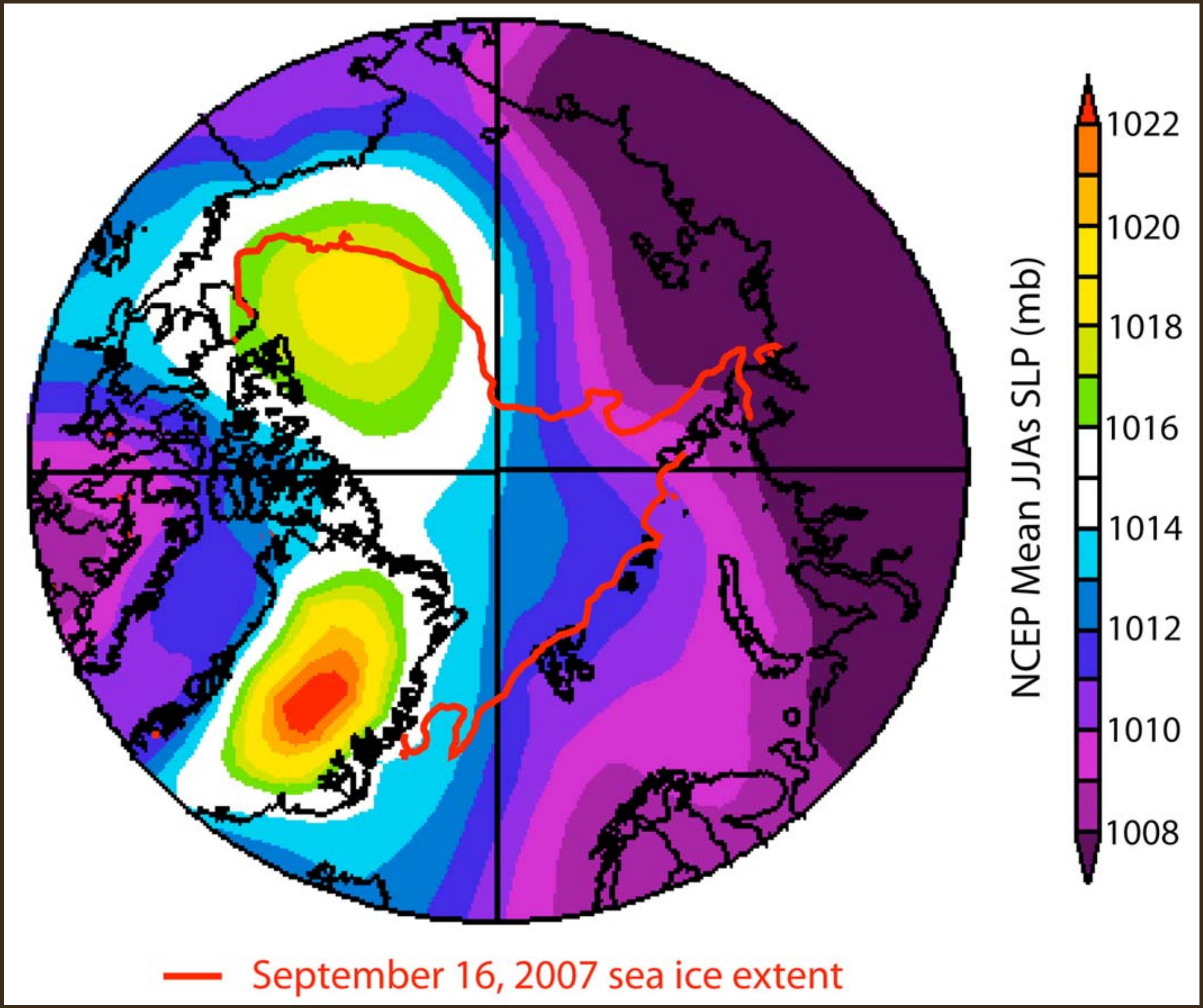
How anomalous were the clouds?



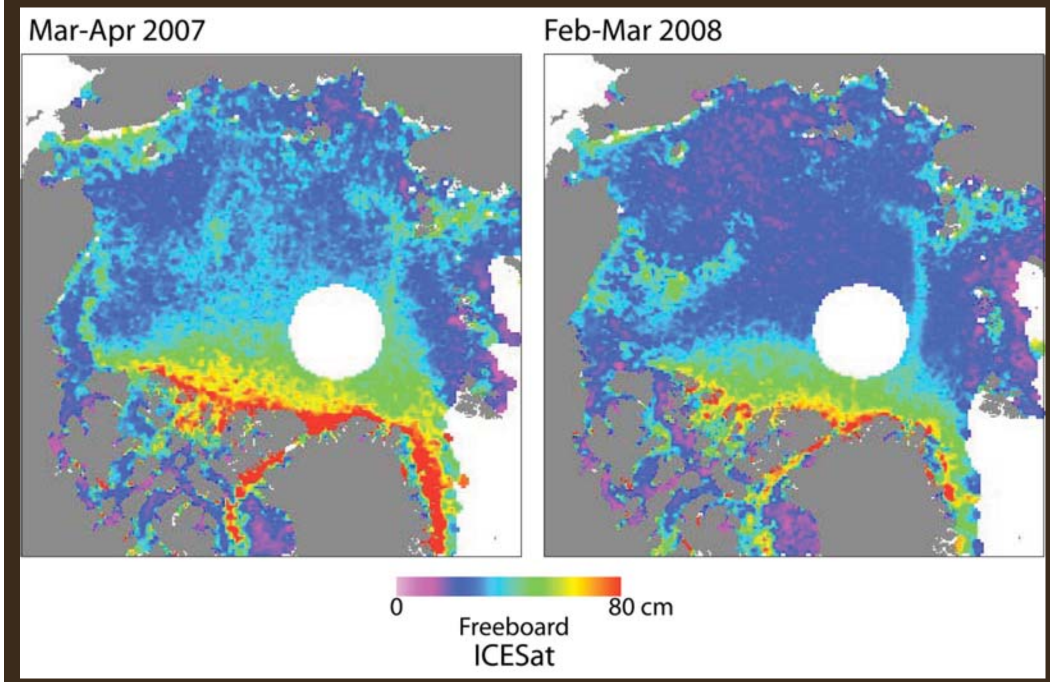
Was the 2007 atmospheric circulation *really* anomalous?

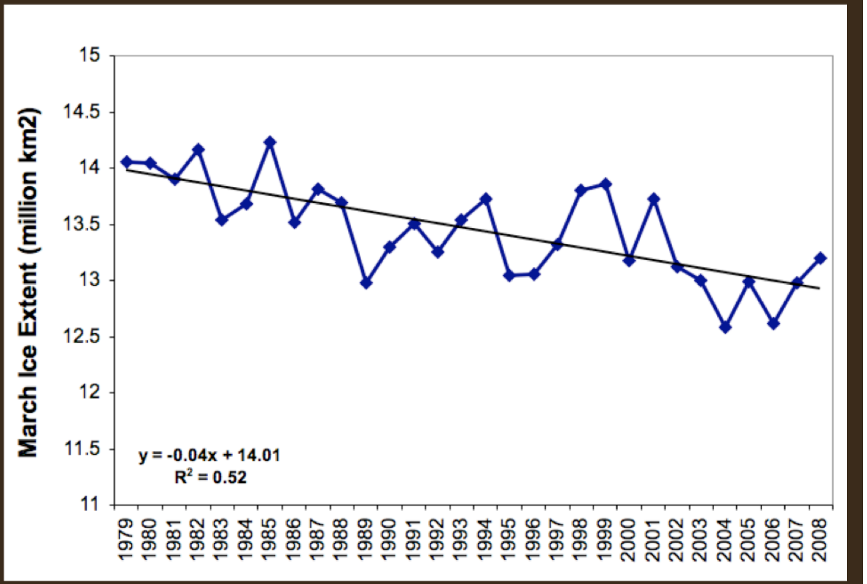


“A perfect storm” for ice loss in 2007



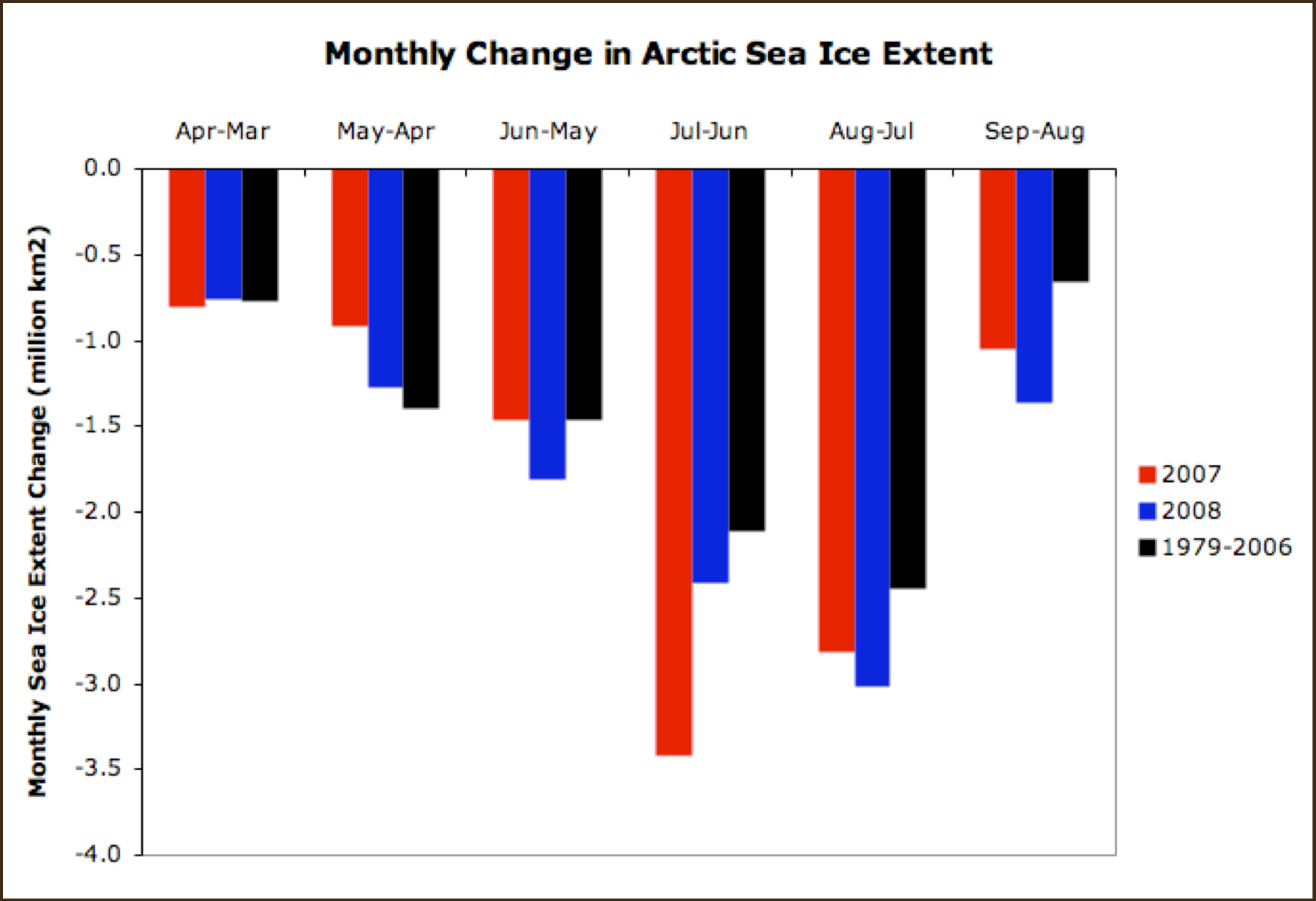
Thin ice
March 2008





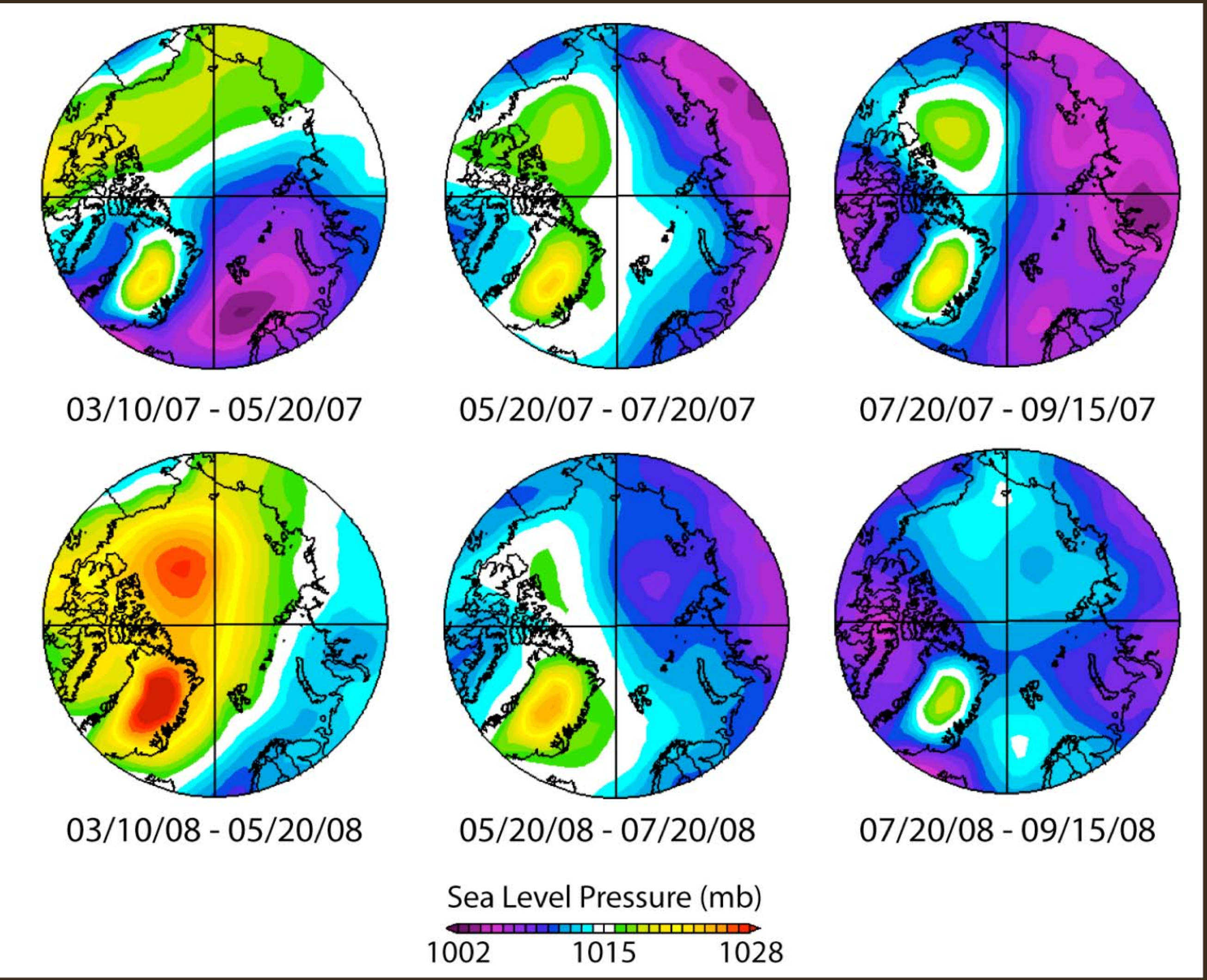
Credit: NSIDC, Ron Kwok (JPL)

Monthly ice loss timeseries

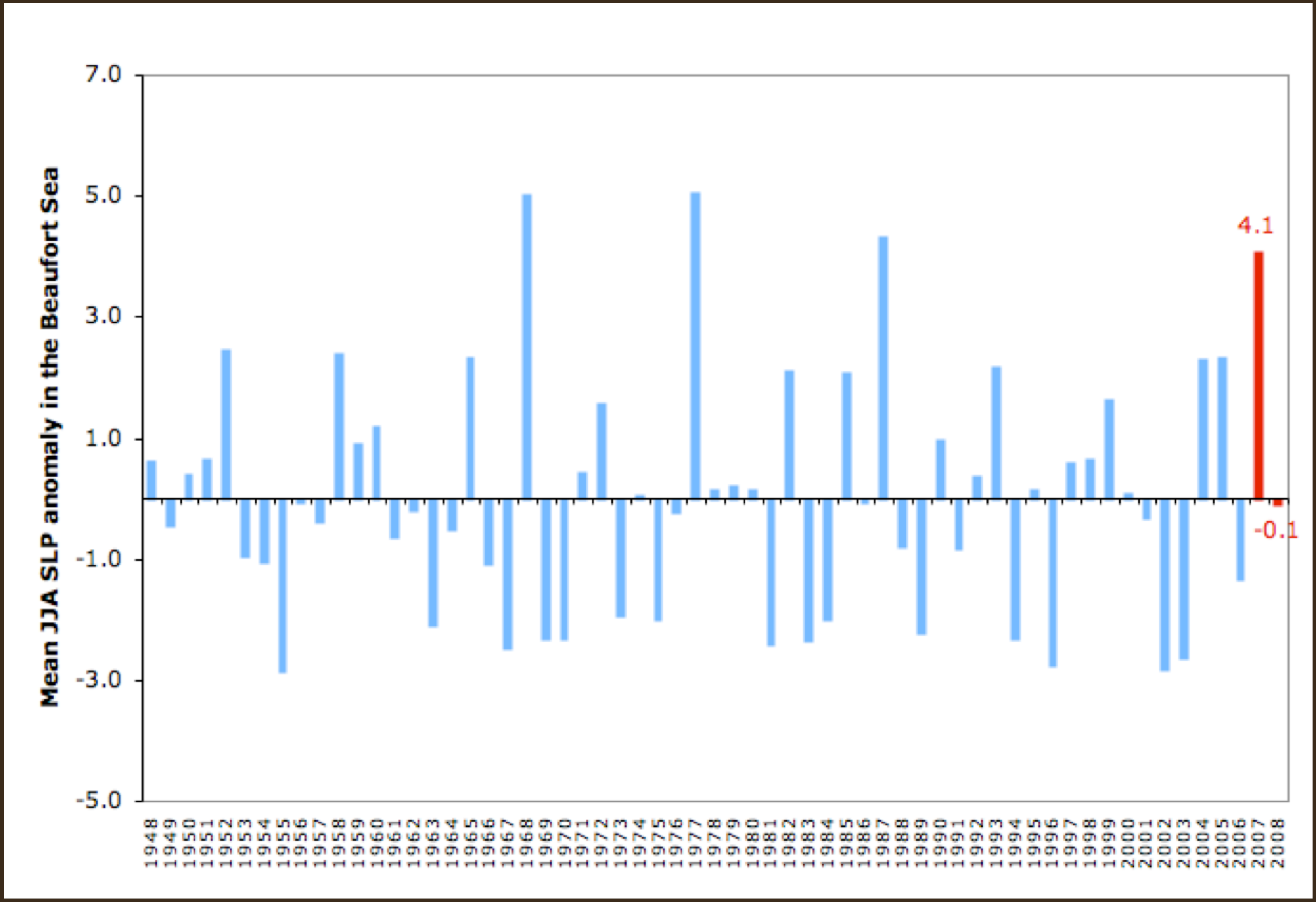


Summer atmospheric circulation

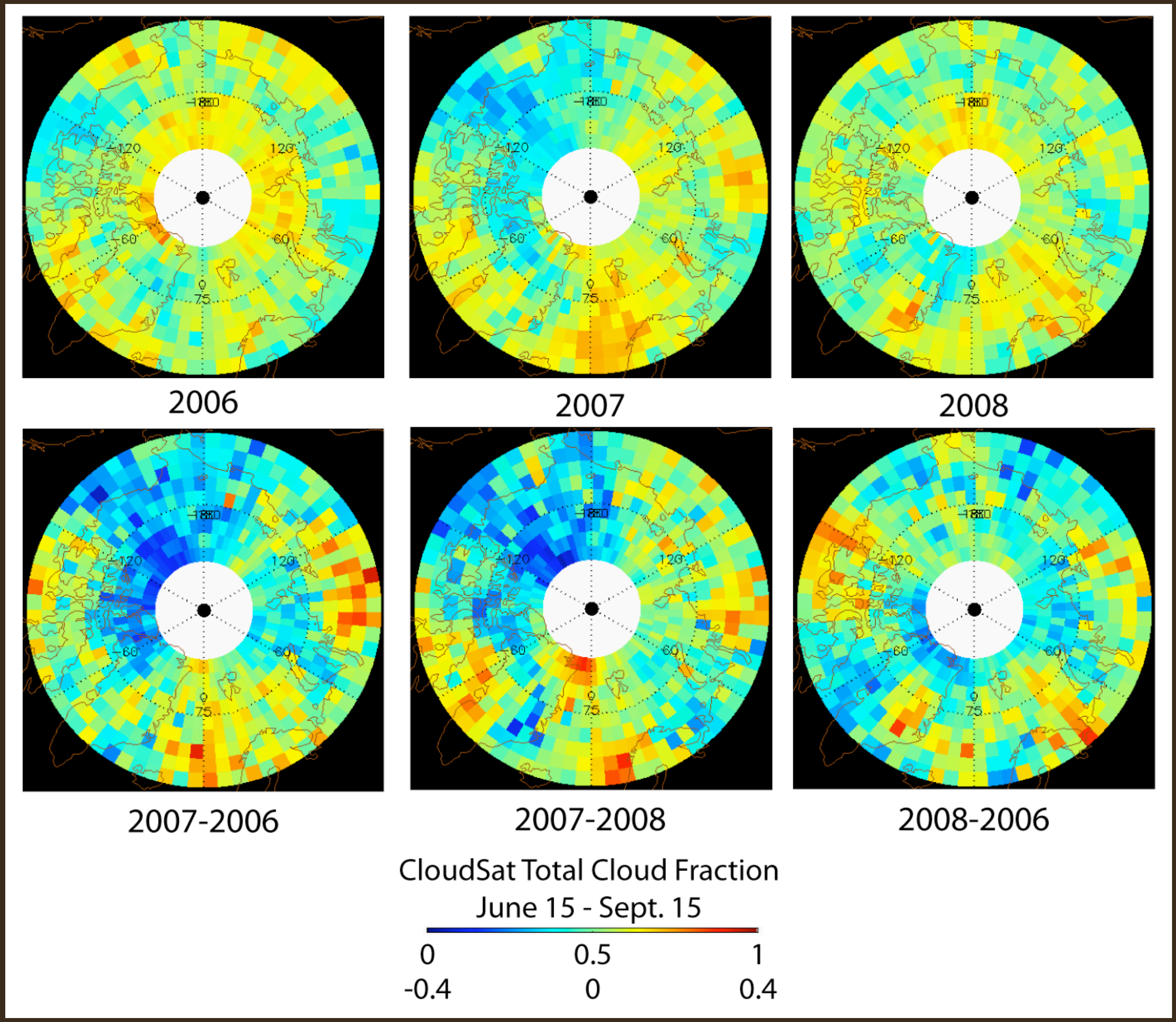
2007 vs. 2008



Was the 2008 Beaufort SLP anomalous?



Were the 2008 clouds anomalous?



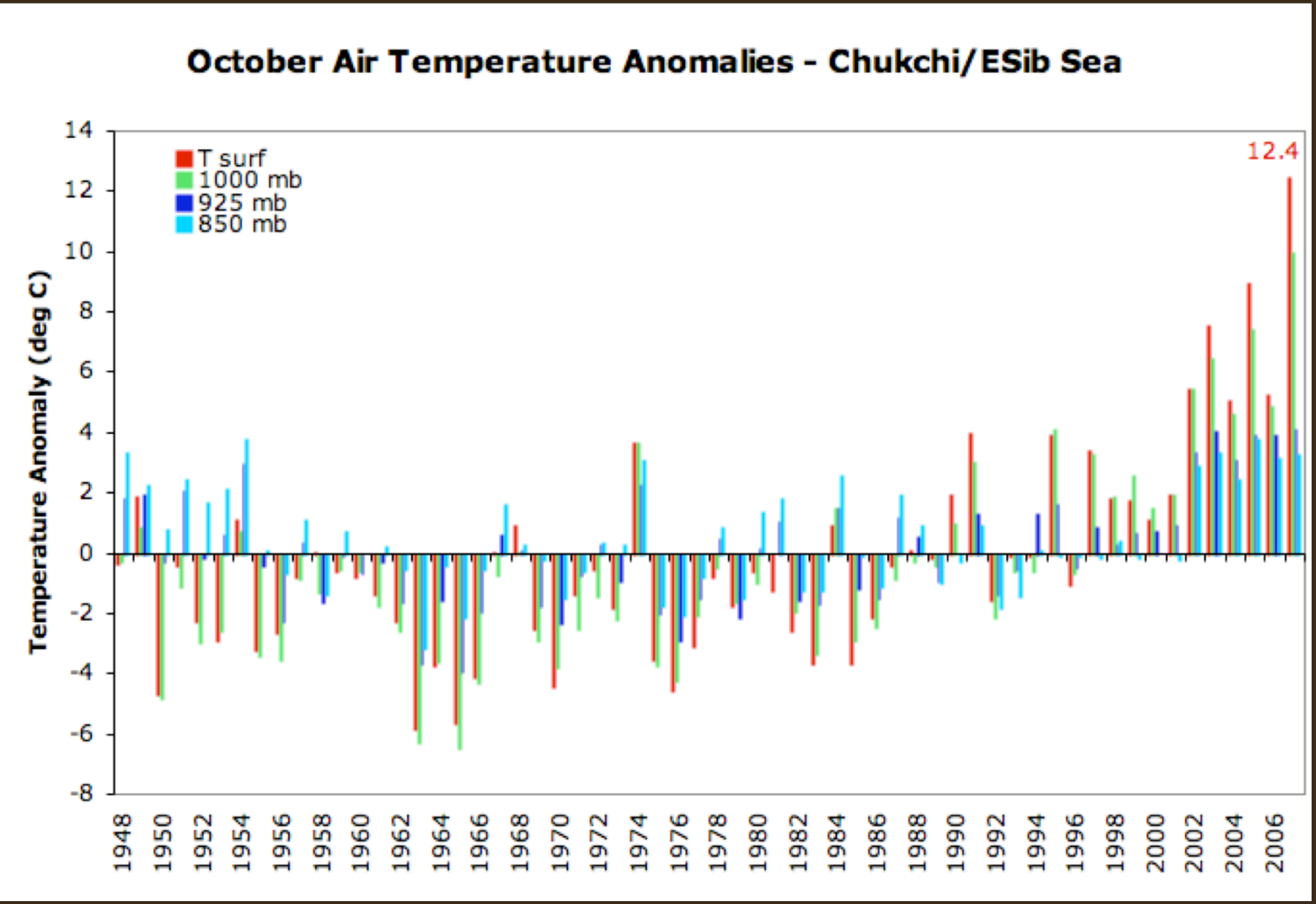
Despite relatively "normal" atmospheric forcing, 2008 had the 2nd lowest Arctic sea ice extent on record.

Effects of declining sea ice

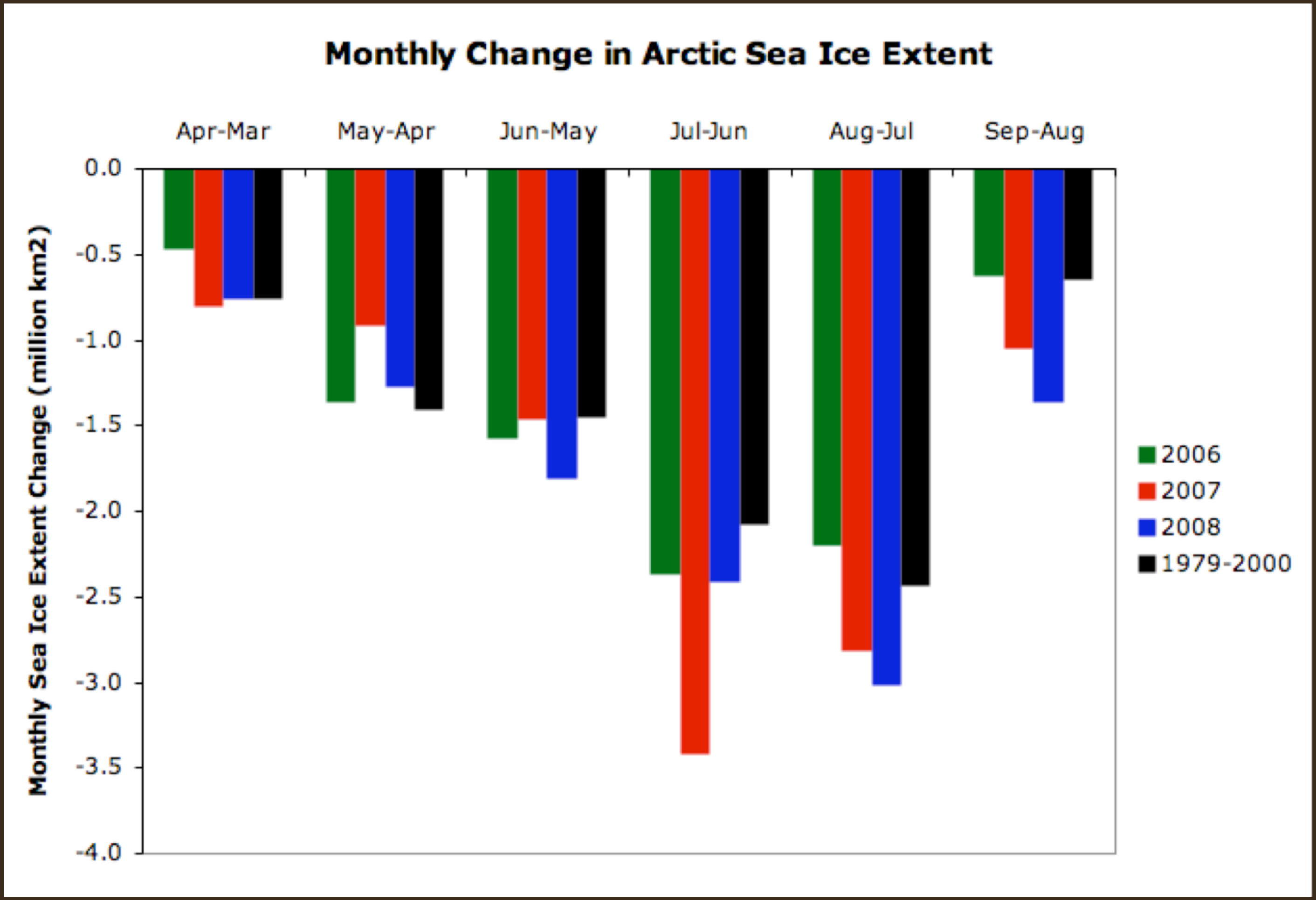
- Summer ice extent decreases

- Summer ocean temperature increases

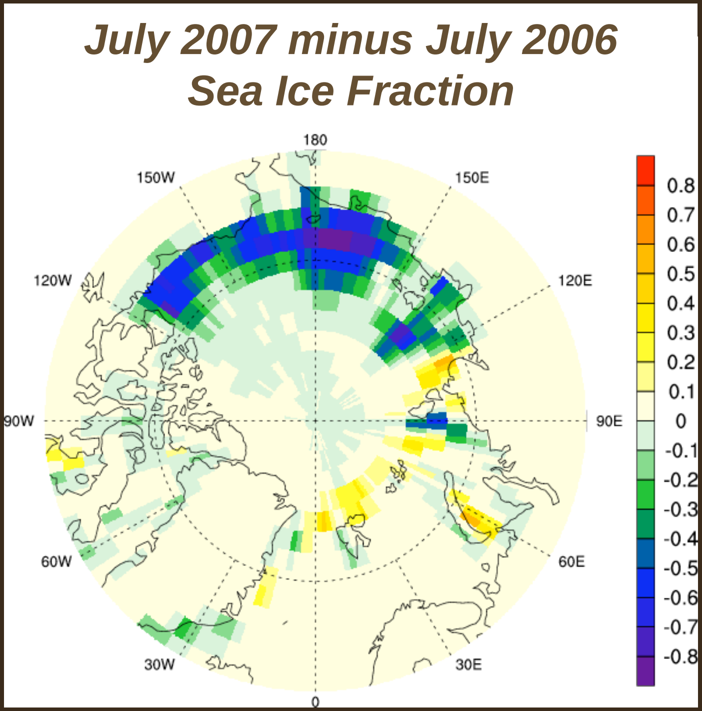
- Fall air temperature increases



1. New observations and tools
2. Observed atm forcing on sea ice loss
3. **Arctic CAM-DART project**



DART-CAM Assimilations



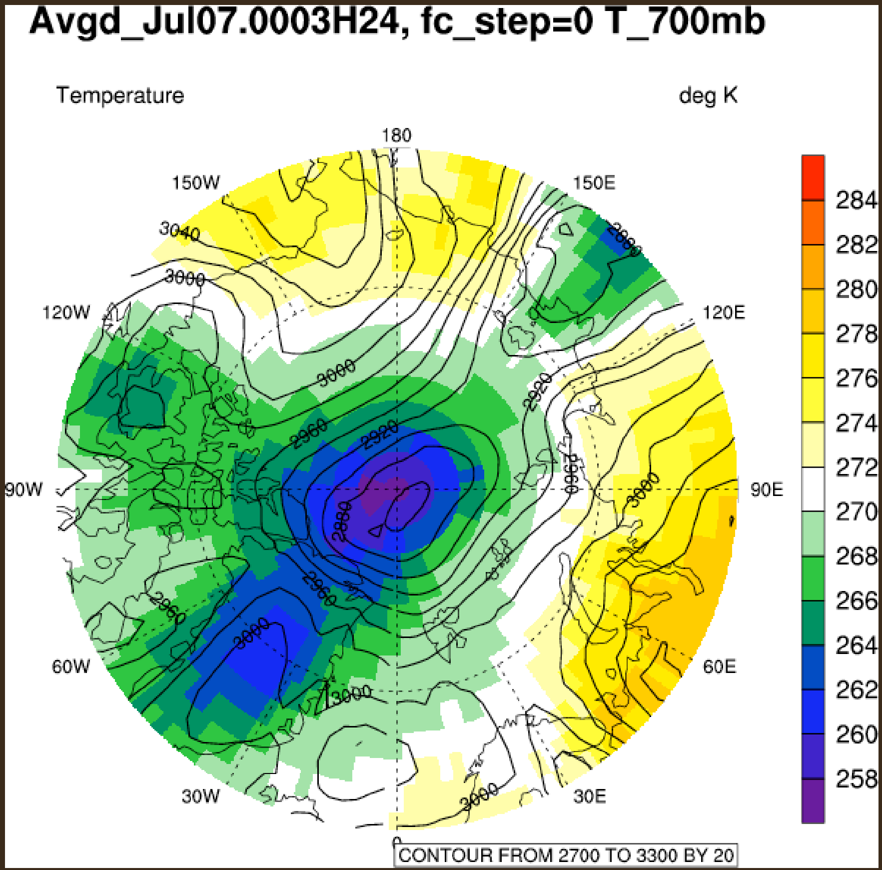
Month	Surface boundary condition
July 2006	observed (Hurrell et al., 2008)
July 2007	observed (Hurrell et al., 2008)

Research Questions

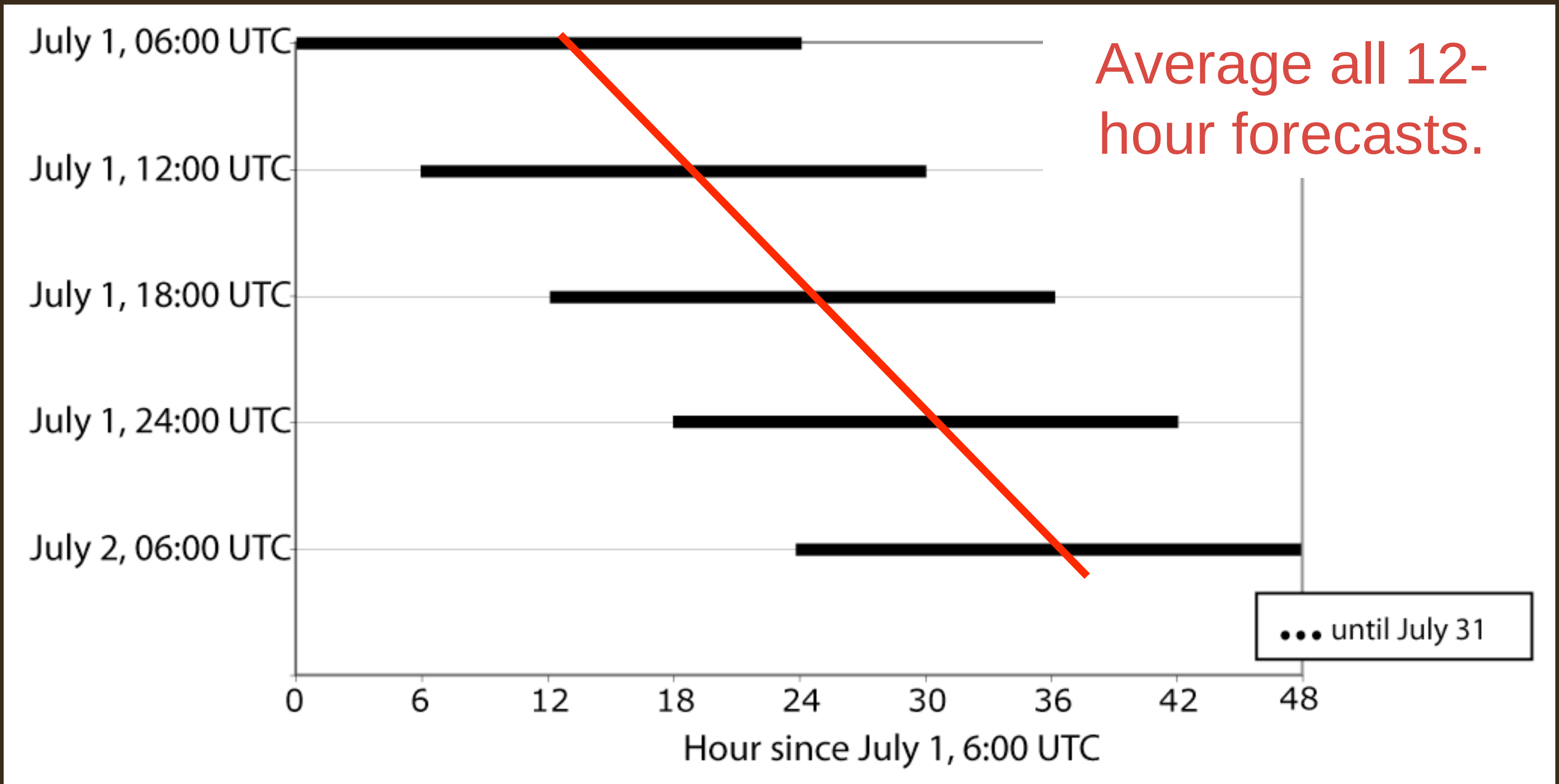
- Does CAM capture changes in atmospheric forcing important for sea ice loss?
- Does the surface affect the atmospheric forcing on sea ice loss in CAM?

CAM forecasts with DART initialization

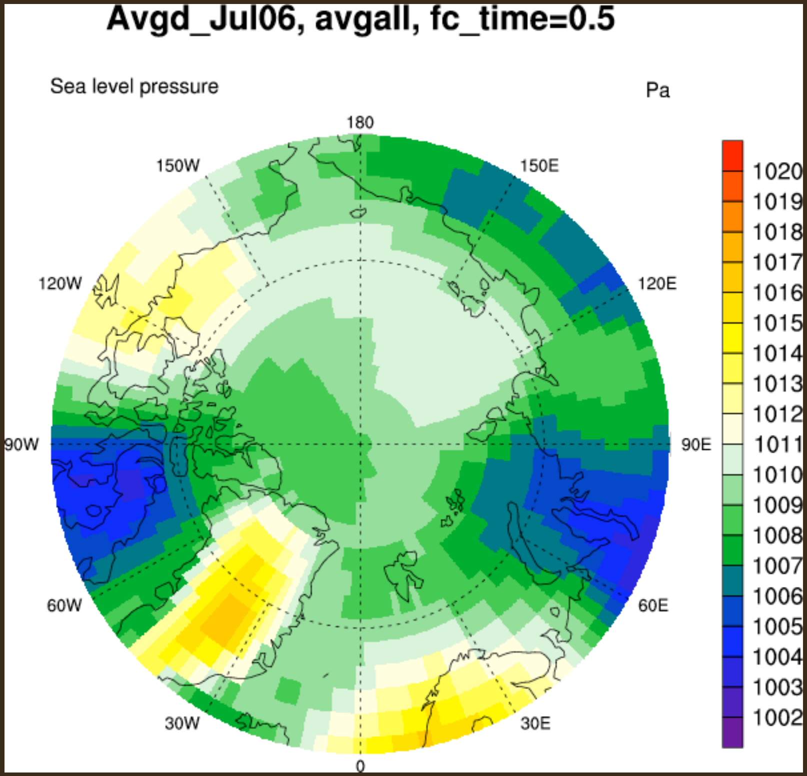
July 3, 24:00 UTC
700 mb Temperature (colors) and
Geopotential Height (contours)

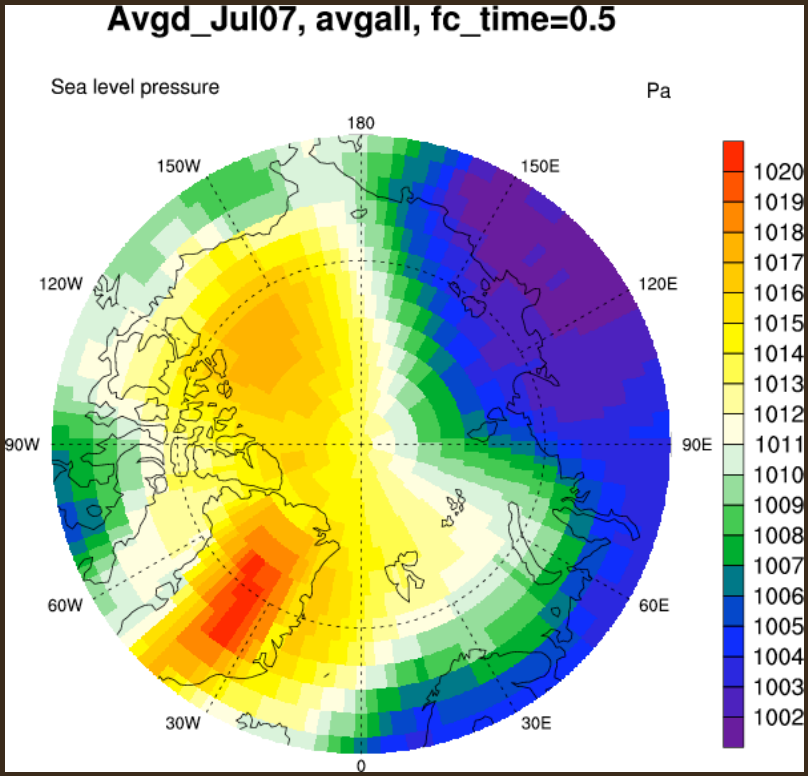


From CAM forecasts to CAM monthly averages…



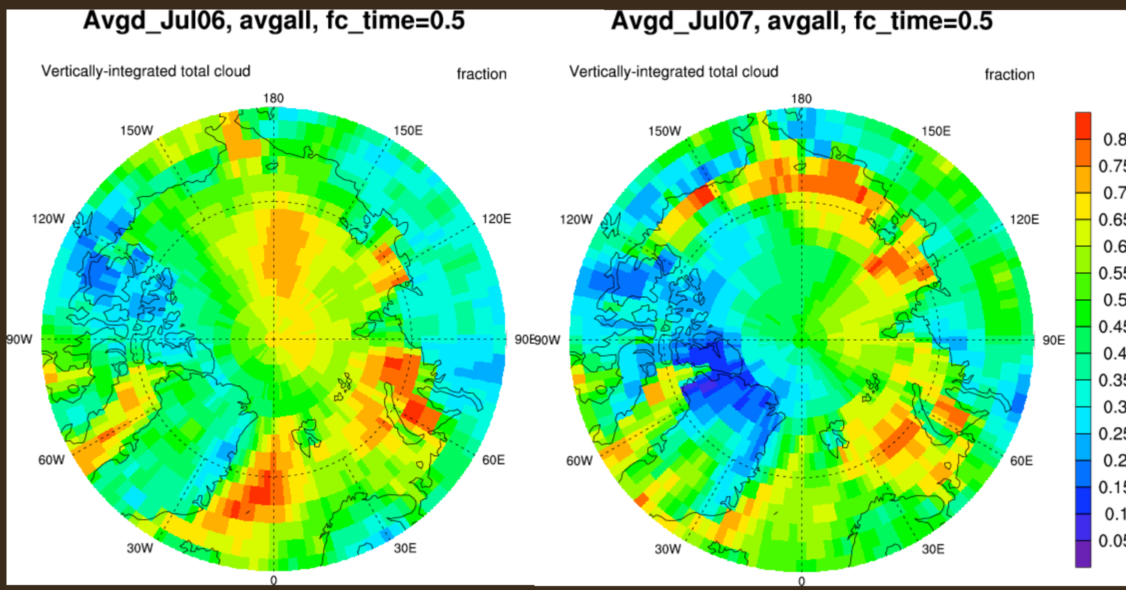
CAM monthly mean SLP
July06 vs. July07

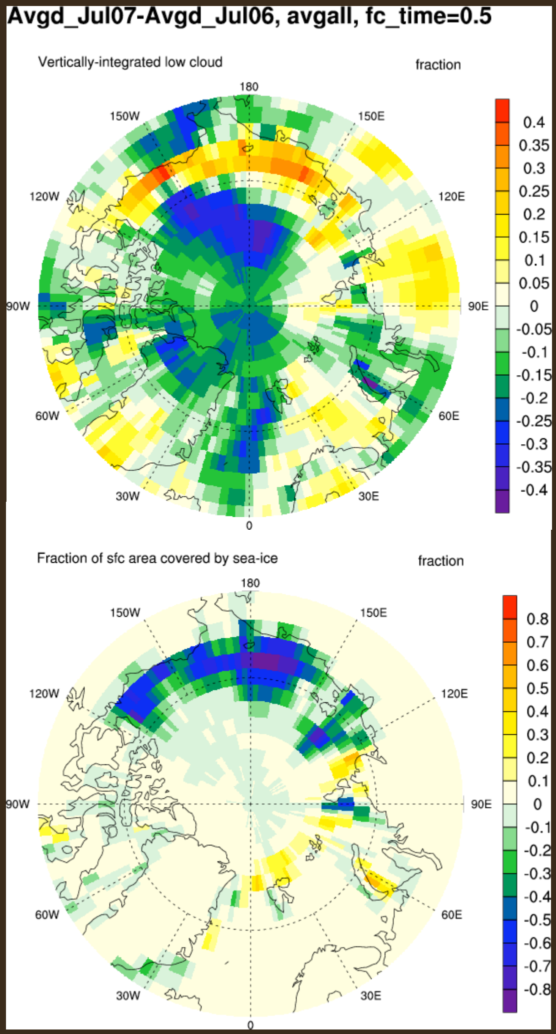




CAM forecasts show large differences in mean sea level pressure fields.

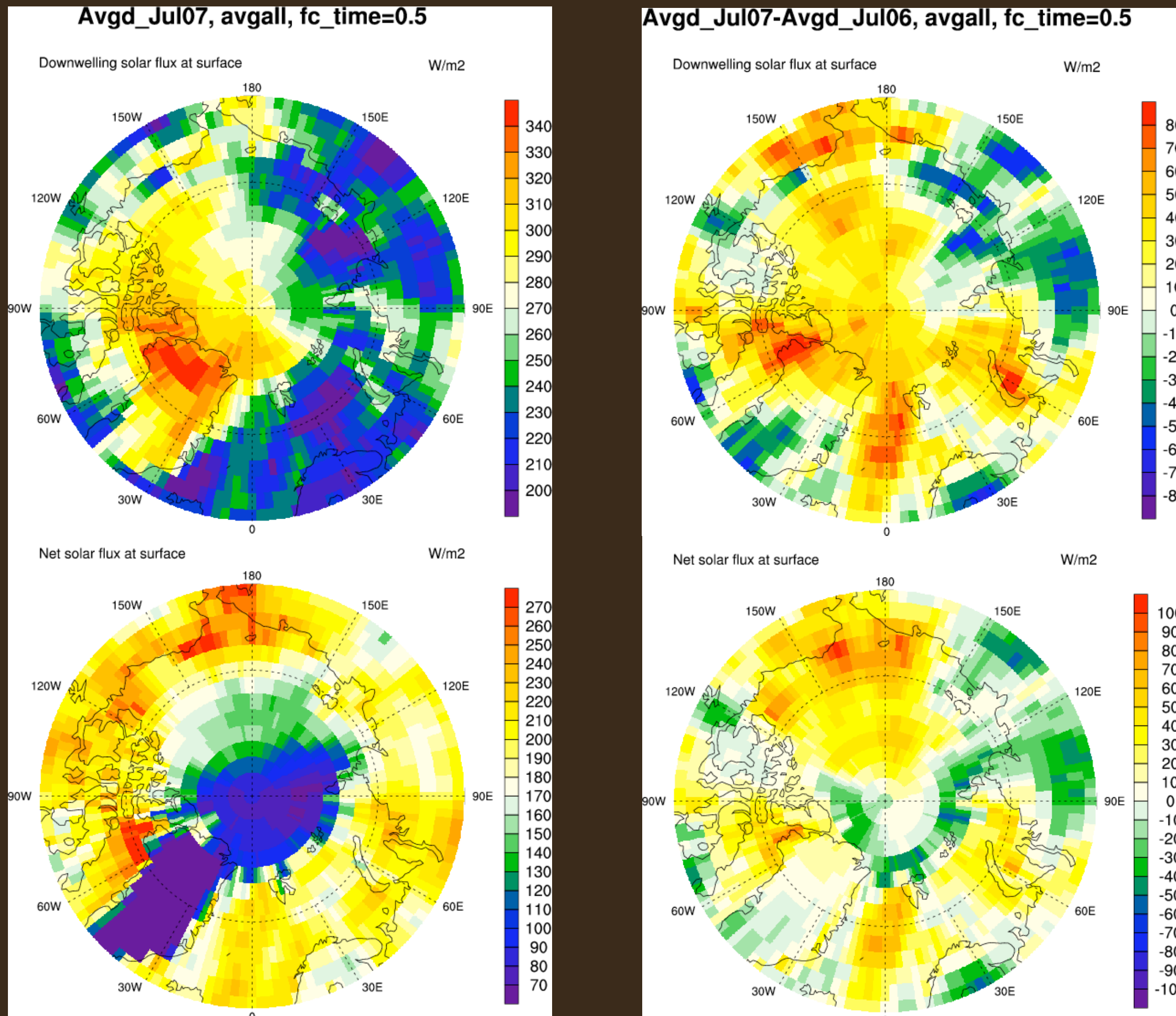
CAM-forecasted clouds





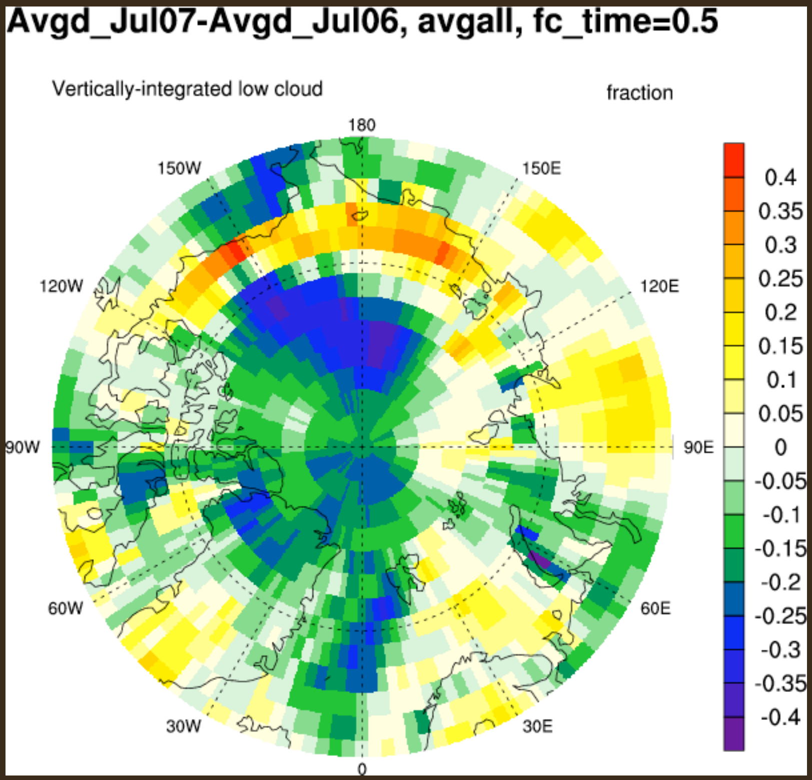
July 2007 had cloud decreases under high SLP, but cloud increases over the ice-free ocean.

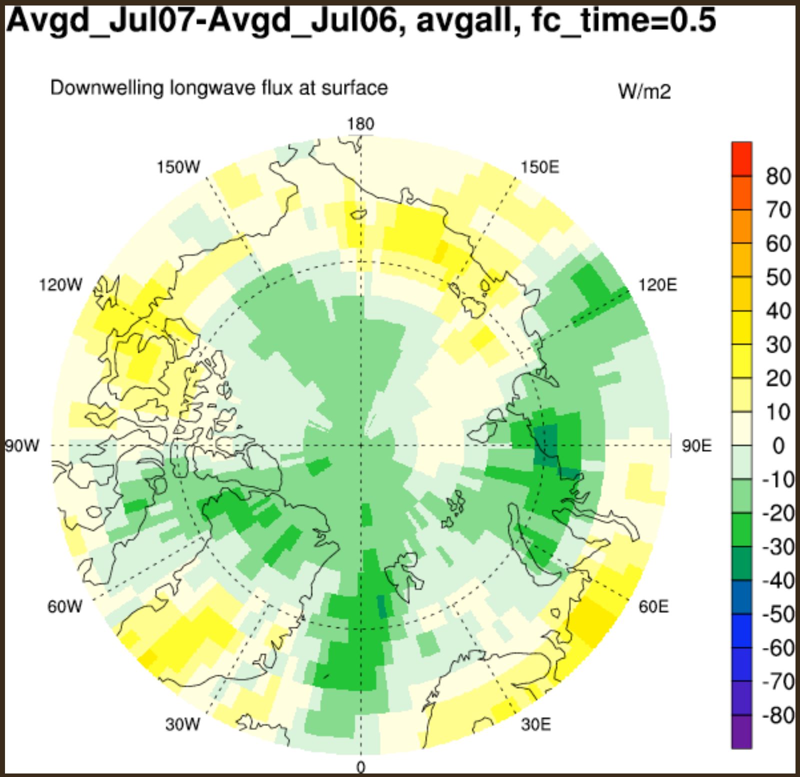
CAM-forecasted shortwave radiation



CAM downwelling and net surface solar radiation responded to cloud changes and surface albedo decreases.

CAM-forecasted longwave radiation





Surface downwelling LW radiation changes related to low cloud changes.

CAM-forecasted clouds and radiation

July07 minus July06

	Arctic Ocean 70-90 N	Western Pacific 70-90 N, 180-240 E	Eastern Pacific 70-75 N,150-180 E
Sea ice area fraction	-0.03	-0.11	-0.49
Total cloud cover	-10%	-13%	+17%
Low cloud cover	-10%	-12%	+20%
Downwelling SW (Wm^{-2})	+28	+33	-13
Net SW (Wm^{-2})	+11	+32	+32
Downwelling LW (Wm^{-2})	-8	- 7	+19

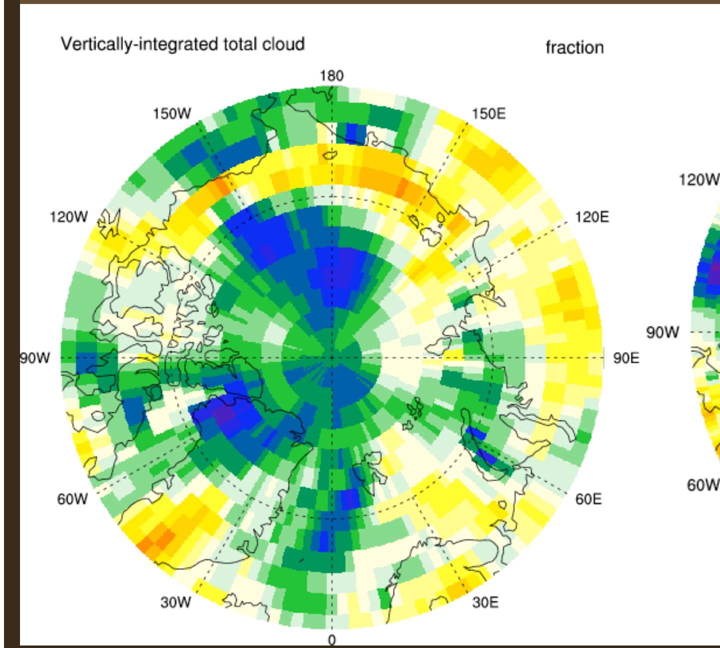
Overall, July 2007 had fewer clouds, more downwelling and absorbed shortwave radiation, and less downwelling longwave radiation.

Over open water, 2007 had more clouds, less downwelling shortwave radiation, more absorbed shortwave radiation, and more downwelling longwave radiation.

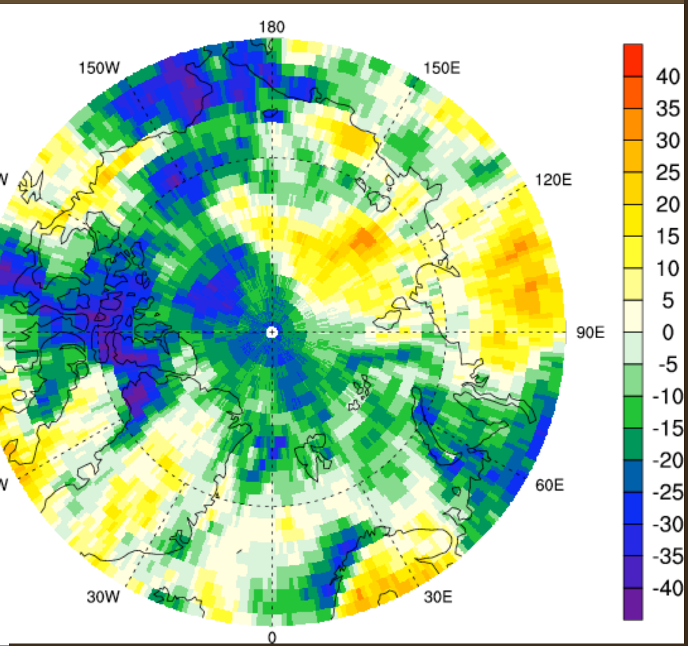
Modeled vs. observed cloud changes

July 2007 minus July 2006

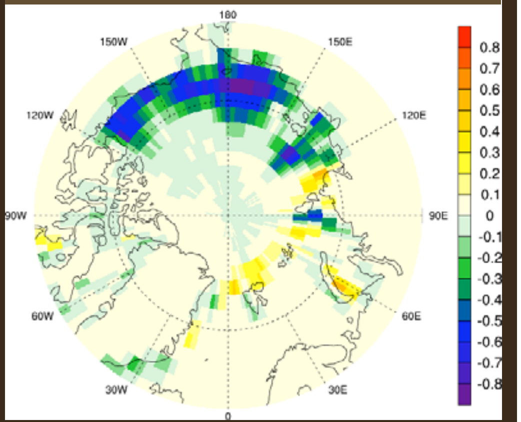
CAM Total Cloud Changes



MODIS Terra Cloud Changes



Sea Ice Area Fraction Changes



Unlike CAM, MODIS shows variability in the cloud response over open water.

Summary

- 2007 was a ‘perfect storm’ for sea ice loss.
- 2008 had the 2nd lowest ice extent with relatively ‘normal’ atmospheric forcing.
- The timing of ice loss matters, and can be used to understand ice loss forcing mechanisms.
- CAM forecasts revealed low cloud increases over open water during July 2007. This negative feedback on sea ice loss was not seen in the 2007 A-train satellite observations.